EESD
2016
4-7 September
Bruges, Belgium

# PROCEEDINGS

## 8TH CONFERENCE ON ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

## BUILDING A CIRCULAR ECONOMY TOGETHER

4 – 7 SEPTEMBER 2016 BRUGES BELGIUM

UNDER THE NATIONAL PATRONAGE OF UNESCO

United Nations
Educational, Scientific and
Cultural Organization

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ISBN: 978-90-903-0131-0
D/2016/14.073/1

**Reference for literature:**
Mazijn, B. (Ed.). 2016. *EESD2016 – Proceedings of the 8th International Conference on Engineering Education for Sustainable Development (Bruges, 4-7 September 2016) – Building a circular economy together*. Instituut vóór Duurzame Ontwikkeling vzw, Brugge.

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# Acknowledgments

The conference organisers would like to thank everybody who has contributed to the preparation, the organisation and the follow-up of EESD2016, especially the Local Academic Partner Committee, the International Committee of Wise Men and the International Scientific Committee.

The conference would not have been possible without the practical support of Meeting in Bruges, PCO Semico and HOWest.

EESD2016 has been sponsored by grants from the Scientific Community, Partners in the Public Sector and Partners in the Private Sector. They are listed at the end of this publication.

## Conference Coordinator

Bernard Mazijn, Institute for Sustainable Development, a non-for-profit organisation in Bruges, and Ghent University (Belgium)

## International Committee of Wise Men

Expertise and experience of colleagues who organised a previous EESD-conference was of utmost value for the current organisers. Thei input at all stages when preparing for EESD 2016 is very much appreciated. Even the wisdom of a colleague who left us to early still resonate in what we are doing.

| | | | | |
|---|---|---|---|---|
| **1st EESD-conference (Delft)** | Leo | Jansen | TU Delft | 23/6/1934 – 16/8/2012, in memoriam |
| | Karel | Mulder | The Hague University of Applied Science, TU Delft & IDO vzw | |
| **2nd EESD-conference (Barcelona)** | Didac | Ferer | UPC Barcelona | |
| | Jordi | Segalas | UPC Barcelona | |
| **3rd EESD-conference (Lyon)** | Pierre | Moszkowicz | INSA Lyon | |
| | Corinne | Subai | INSA Lyon | |
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| | Friedrich | Zimmermann | University of Graz | |
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| **7th EESD-conference (Vancouver)** | Thomas | Froese | UBC Vancouver | |
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| **8th EESD-conference (Bruges)** | Luk | Van Langenhove | IDO vzw | |
| | Rietje | Van Dam - Mieras | IDO vzw | |
| | Bernard | Mazijn | IDO vzw | |

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- Van Acker Karel, Faculty of Engineering Science, KU Leuven
- Van Langenhove Luk, Institute for European Studies, Free University Brussels

# Preface

It has been a privilege to organise the 8th International Conference on 'Engineering Education for Sustainable Development' from 4-7 September, 2016 in Bruges, Belgium (EESD 2016). Organising an EESD is as well an engagement in contributing to sustainable development.

Being involved from the start in this series of conferences, we have seen maturing the understanding of the 7 W-questions. **W**hat is EESD all about? **W**here is EESD taking place? **W**ho is a champion in EESD? Ho**w** is EESD implemented? **W**hy is EESD important? **W**hat if EESD doesn't work out? To **w**hom is EESD addressed?

Attending an EESD-conference these days, allows you to have a better understanding, to contribute to the further development and, to get feedback from colleagues on your own practices.

Each of the conferences has been focusing on a theme. EESD 2016 addressed the challenges of '**Building a circular economy together**' by questioning the implications for engineering education. Furthermore, at the conference – under the heading of '**Beyond the triple helix**', beyond an interaction between academia, industry and public authorities – the involvement of other stakeholders in formulating the expectations towards engineers has been debated. These proceedings bring together all information available at EESD2016.

Let me congratulate again the price winners for the best papers and poster. Furthermore I wish the organisers of the following EESD-International Conferences all the best!

Bernard MAZIJN, Conference Coordinator

# Introduction

Despite the differences in vision on society, there is a growing recognition that globally several megaforces can be observed that have an impact on the society at regional and local level. Population growth, urbanization and the increase in the purchasing power of the middle class in emerging countries lead to an additional huge demand for resources (fossil fuels, metals, biomass ...) in order to meet the production and consumption needs. The results are volatile but rising prices and uncertainties in supply. Facing the threats of climate change societies have been choosing, inter alia, to expand the sector of renewable energy. As a result all these developments the demand for resources (metals, biomass …) has indeed further increased. The pressure on ecosystems is immense, food systems are threatened, biodiversity is decreasing, etc. From this observation it becomes clear that the current globalised throughput economy cannot be placed in a context of sustainable development and should urgently be replaced by a circular economy.

Succeeding in a transition never experienced before and on a short notice will require a societal support from all stakeholders. Therefore the so-called triple helix, where university, industry and government are setting up relationships, is not suitable anymore for the challenges ahead of us: all actors need to be involved in this technological and societal innovation.[1] Moving 'Beyond the triple helix' means the involvement as well of the civil society at large, the trade unions, etc.[2]

The engineer needs to develop capabilities to perform within these complex settings of society. Formal engineering education is the start to prepare young people for this challenging task. Lifelong learning should train engineers on the job to take into account these challenges in their daily work.

The call for submissions and the programme of EESD 2016 has been organised along these lines.

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The conference organisers asked authors and delegates to consider the following key questions regarding **engineering education for sustainable development** when submitting an abstract and subsequently a paper:

- *Circular Economy*: how is design for scarcity or recycling for scarcity introduced into the curriculum of engineers? what about the inter- and intrasectoral competition for resources?
- *Technological and societal innovation*: how does it influence the curriculum of engineers? what about stakeholder involvement? what is the role of engineering in the sustainability transition processes? how is engineering education dealing with it?
- *Organisational change:* how technical universities/faculties/departments can change their management in function of EESD?
- *Multi-, inter- and transdisciplinarity*: how are courses set up for developing these capabilities? how far does this multi-, inter- and transdisciplinarity work in practice?

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[1] "The concept of the Triple Helix of university-industry-government relationships initiated in the 1990s by Etzkowitz (1993) and Etzkowitz and Leydesdorff (1995), encompassing elements of precursor works by Lowe (1982) and Sábato and Mackenzi (1982), interprets the shift from a dominating industry-government dyad in the Industrial Society to a growing triadic relationship between university-industry-government in the Knowledge Society." dixit the Triple Helix Research Group of the Stanford University (see http://triplehelix.stanford.edu/3helix_concept).

[2] E.g. Carayannis E. and Rakhmatullin R., The Quadruple/Quintuple Innovation Helixes and Smart Specialisation
Strategies for Sustainable and Inclusive Growth in Europe and beyond, pp. 42-60; in European Commission, (2014), Open Innovation 2.0 – Yearbook 2014. European Commission, Directorate-General for Communications Networks, Content and Technology, 149 pp.

- *Innovative teaching technology/organisation*: are there good examples in engineering education of 'massive open online courses' (MOOCs), 'small private online courses' (SPOC's), 'open educational resources' (OER's), virtual communities of practise (VCoP's), etc.?
- *Lifelong learning*: are the examples of on the job training to cope with the described challenges?

The papers have been the basis for the presentations during the conference. Sessions were organised around working streams.

* * * * *

The proceedings below are listing the papers presented at the different sessions during the conference. In annex one can find the detailed programme, incl. a brief description of specific workshops. Next the posters are presented. Just below you will find the price winners.

Based on the presentations during the parallel sessions, including the interactions, the **Main findings** of EESD2016 are summarised. They are considered to serve as an input for EESD and its next conference in particular.

At the very end the partners that supported EESD2016 are presented.

Have a good reading!

# Price winners

At each conference price winners for the best papers and best poster are awarded. During EESD2016 the selection is made by a jury composed of the members of the International Committee of Wise Men, i.e. the organisers of the past, current and next EESD-International Conferences. Prof. dr. ir. Karel Mulder acted as the chair.

The input for the jury was an evaluation on the one hand of the session chairs and on the other hand of members of the jury attending the respective sessions. During a full two hour meeting of the jury before the Closing Session of EESD2016 a selection was made. As explained by the chair of the jury it was not an easy task, because there were many excellent paper and poster presentations.

* * * * *

The award for **the best EESD2016 paper and presentation with a focus on education**, **the famous so-called Leo Jansen price**, goes to …:

**Thomas J. Siller, Gearold R. Johnson and Russ Korte** from the **Colorado State University (United States of America)** for their paper and presentation on **'Is there a role for interprofessional education (IPE) in the future of engineering education for sustainable development?'**

* * * * *

The award for **the best EESD2016 paper and presentation with a focus on research** goes to …:

**Sara Trulsson, Daniel Franzén and Jon-Erik Dahlin** from **KTH Royal Institute of Technology (Sweden)** for their paper and presentation on **'Active learning as a supportive teaching method to address climate change in higher education.'**

* * * * *

The award for **the best EESD2016 poster and short presentation** goes to …:

**Luis S. Vargas, Claudia A. Mac Lean, Alberto de la Fuente and Jorge Campos** from the **University of Chile (Chile)** for their poster and short presentation on **'Towards a culture of adopting sustainability energy at the Faculty of Physical and Mathematical Sciences of the University of Chile.'**

* * * * *

Congratulations on behalf of jury and the organisers of EESD2016. These papers and poster can be read below in the *Proceedings*.

# Main findings

Based on the input received through the submitted papers the presentations have been organised 4 streams of sessions in parallel

- A-stream is focussing on circular economy, design and resources; LCA for a circular economy fits as well into that stream;
- B-stream is about 'Outside the box thinking'; in other words, it is about these issues that are not common in engineering education;
- C-stream is the core issue of all EESD-conferences: (barriers to) (innovative) teaching, while reforming programmes and curricula;
- D-stream is have sessions grouped according to sectors and/or disciplines.

Each presenter did have 15 minutes for presentation, followed by max. 5 minutes of 'Questions for clarification'. At the end of the session there was almost a half hour for interaction between the presenters and the audience. The session chair summarized the main findings of the session in bullet points: colleagues appointed as stream coordinators presented at the end of the conference the plenary the summary per session as reflected below.

## Sessions Stream A
## Focus on circular economy, design and resources

**Stream Coordinators:** Adam de Eyto (University of Limerick, IE) and Edmond Byrne (University College Cork, IE)

**Session Chairs:**

- A1 - Gijs du Lain (Ghent University, BE)
- A2 - Karel Van Acker (KU Leuven, BE)
- A3 - Shady Attia (Université de Liège, BE)
- A4 - Adam de Eyto (University of Limerick, IE)
- A5 - Naoko Ellis (UBC Vancouver, CAN)

The presentations in the 5 sessions in Stream A were primarily focussing on Circular Economy and Design within the context of EESD. LCA for a circular economy was a focus in one of the sessions.

The Stream Coordinators reported back to the plenary as follows:

- Interdisciplinartity is essential but not easy
- SD and CE is still not sufficiently embedded in the curriculum
- T Shaped Professionals are needed to address the challenges.
- Need to connect with 'real life' and stakeholders
- Collaboration and Coordination between faculty is still week
- There is often a disconnect between Undergrad and post grad courses with respect to SD
- The use of games is helpful with interdisciplinary groups
- Real world examples and onsite study visits animate the issues quickly
- Discussions on how Circular Economy fits into Sustainable Development highlighting multiple dimensions of CE reflecting location and context
- How is social LCA being handled? Design education and service system are inherently closer to societal aspects of sustainability
- Creating LCA case study repository. Can EESD body curate open source material related to LCA case studies?

# Session Stream B
# 'Outside the box thinking'

**Stream Coordinators:** Richard Vaz (Worcester Polytechnic Institute, USA) and Jiusto Scott (Worcester Polytechnic Institute, USA)

**Session Chairs:**

- B1 - Richard Vaz (Worcester Polytechnic Institute, USA)
- B2 - Luk Van Langenhove (UNU-CRIS & VUB, BE)
- B3 - Kees Vromans (Emeritus HAS University Den Bosch, NL)
- B4 - Scott Jiusto (Worcester Polytechnic Institute, USA)
- B5 - Nadine Gouzée (Club of Rome - EU Chapter, BE)

The presentations in the 5 sessions of Stream B, 'Outside the box thinking', focussed on issues that are not common in engineering education, such as 'global issues', 'stakeholders', 'ethical and social issues', 'social Responsibility' and 'transdisciplinarity'.

The Stream Coordinators were stressing the following points in the plenary:

- EESD requires supporting student development across a wide spectrum of skills, abilities, conceptual lenses, and personal qualities;
- 'Modularity' of many curricular examples signals the constraints educators experience trying to deliver 'simplified' introductions to deep, challenging domains;
- How do we foster discussion and progress toward more fundamental institutional change?

Furthermore, the interaction during the sessions resulted in the following conclusions from the session chairs:

- In EESD there is need of education on ethics/ethical dilemmas;
- Explosive growth in African cities will demand a new and more effective model for developing engineering talent;
- Can emerging technologies facilitate online access to education in remote rural areas in the developing world?
- How can we prepare the needed generation of sustainability minded engineers?
- Sharing knowledge with society is important for achieving sustainable development;
- Universities need to reach out to society through their students;
- Bringing in stakeholders challenges the disciplinary silos of the university.

# Sessions Stream C
# Teaching, while reforming programmes/curricula

**Stream Coordinators:** Rietje van Dam-Mieras (Emeritus Leiden University, NL) and Pritpal Singh (Villanova University, USA)

**Session Chairs:**

- C1 - Angélique Léonard (Université de Liège, BE)
- C2 - Rietje van Dam-Mieras (Emeritus Leiden University, NL)
- C3 - Jordi Segalas (UPC Barcelona, ES)
- C4 – Karin Edvardsson Björnberg (KTH Royal Institute of Technology, S)
- C5 - Pritpal Singh (Villanova University, USA)
- C6 – Rietje van Dam-Mieras (Emeritus Leiden University, NL)

The presentations in the 6 sessions of Stream C were addressing the core question of all EESD-conferences: 'What is/are (the barriers to) (innovative) teaching?' The sessions were organised along the following lines: 'overcoming barriers for EESD', 'lifelong learning', 'curricula, programmes and accreditation’, ‘student evaluation’, ‘innovative teaching’ …

The Stream Coordinators structured the conclusions of the interaction during the sessions as follows:

With regard to ‘***Teaching***’:

- Bridges need to be made across disciplines to integrate SD; e.g. co-teaching, co-case studies; faculty from different disciplines are especially important in first year courses.
- Content is everywhere – learning is sharing (mentoring/coaching is important)
- Research on learning environments to satisfy different learning styles; educate the educators.

With regard to ‘***Curricula and Delivery Methods and Learning Environments***’:

- Important aspects: learning to deal with complexity and authenticity of the learning environment; global viewpoint -> local considerations.
- The educational system has to reorganize to have students reach their full potential (can use different delivery methods such as MOOCs, flipped classes, ICT technologies)
- Incorporating sustainability principles into engineering  design projects

With regards to ‘***Accreditation and Assessment***’:

- Accreditation is a driving force for EESD in France; working out accreditation criteria. But resistance to change in Ireland because of domination of traditional engineers in setting accreditation criteria.
- Curricula assessment should focus on learning outcomes; criteria for curricular assessment may influence the results and therefore may not make the results comparable.
- Upper university administrative support for SD programs is important.

# Sessions Stream D
# Focus on sectors and/or disciplines

**Stream Coordinators:** Iris De Graeve (VUB, BE) and Aurore Degré (Université de Liège, BE)

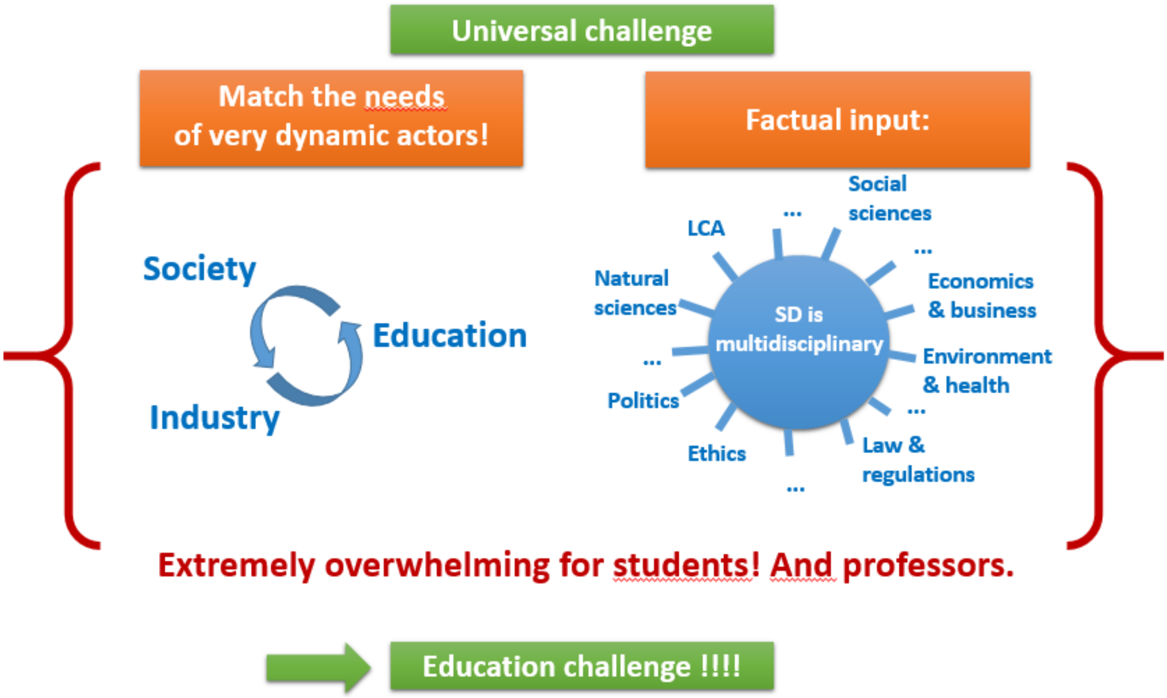
**Session Chairs:**

- D1 - Michel De Paepe (Ghent University, BE)
- D2 - Iris De Graeve (VUB, BE)
- D3 - Peter Goethals (Ghent University, BE)
- D4 – Aurore Degré (Université de Liège, BE)

At an EESD-conference there are always submissions focussing on sectors and/or disciplines. The presentations have been organised in 4 sessions: ‘EESD and Energy’, ‘EESD and Disciplinary Approaches’, ‘EESD and Water et al.’ and ‘EESD and Biosciences’.

In their presentation for the plenary the Stream Coordinators were stressing that from now on the Sustainable Development Goals (SDG’s) will be a guiding set for goals and targets for engineers as well: EESD should help them in developing capabilities.

They analysed the input from the interaction during the different sessions and put it in the following graph:




In conclusion, based on the input they received, they recommended the following approach:

1. ‘Engineering’ approach involves ‘system analysis’: structure the system!
2. Work with tangible case studies that appeal to your students (chocolates, beer ...) and respect their sense of responsibility and need for involvement in the future of our society and world in general!
3. Involve all actors! Let engineering students interact with other faculties and industry.
4. Student participation on all levels, incl. program development.

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Finally the Stream Coordinators recommended to bring these main findings to the next EESD-conference(s) and to invite students (and other actors) to EESD2018.

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**Stream D – Session 3: EESD and Water et al.**

# Educating Engineers for the Circular Economy

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## Abstract

The idea of the Circular Economy is underpinned by systems approaches to the complex issues of sustainability. This requires the adoption of innovative approaches in educating engineering students to take their place in the economy of the future, incorporating systems thinking and collaboration skills. The approach developed, and still developing, in Manchester towards issues of educating engineers for global societal responsibility lends itself well to the embedding of ideas brought together under the heading of 'Circular Economy'. Some of the basic precepts are not new and build on ideas already incorporated in the curriculum, but the dilemma-based approach lends itself to building confidence in tackling complex issues in a multi-disciplinary context where shared understanding is essential to build trust and avoid vulnerability to a lack of flexibility in other parts of the system. This holistic, systemic approach is a vital component of a number of course units in Manchester and the ideas of the circular economy are increasingly becoming embedded in the scenarios that form the basis of skills development and knowledge attainment.

This paper will describe the approach being taken in selected course units in Manchester and their relevance to the wider context, particularly in the context of ideas being developed elsewhere. This will include examples of how the concept is elucidated in practice. The evaluation will include feedback from students on the extent to which this approach has aided their understanding of the processes and practices of the circular economy, together with their ideas about the barriers posed by using the phrase 'circular economy' when dealing with engineers.

## 1 Introduction

### *1.1 Circular Economy and Engineering Education*

The 'Circular Economy (CE)' refers to a model of consumption and production different from the 'linear economy' (make, use, dispose) that has dominated society for decades and is literally unsustainable; we simply cannot continue taking resources from the ground, making them into products and disposing of them somewhere with little regard for the cumulative effects indefinitely. CE is often used synonymously with 'closing loops', in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life. However, the CE is much more than that. It is about creating value for businesses, the economy and ultimately society while minimising resource use and environmental and social impacts via 'system thinking'. From policy makers to household names such as Phillips and Renault the transition from a linear to a circular economy has already begun and looks set to be a big part of our future.

Engineers are 'future builders' and as such, they play a key role in the transition from a linear to a CE. However, to date there is very limited literature disseminating the pedagogical approach and lessons learnt introducing the concept of the CE in the engineering education curriculum. In 2013, Ken Webster, advocate of the CE, emphasised the pedagogic value of "interlocking curriculums" and more "context driven work" when delivering education for understanding the CE. In addition to that, a recent report from the Ellen McArthur Foundation (EMF 2014) suggests adopting a "participatory and a feedback rich learning environment" to develop the learners understanding of core principles of the CE, 'system thinking' and the role of various stakeholders such as businesses, government and society in building a CE.

### *1.2 Circular Economy, Sustainable Development and Engineering Education at the University of Manchester*

At the University of Manchester, over the last 10 years engineering education has been strongly focused on preparing 'future builders': future engineers for global societal responsibility able to fulfil the broad environmental, economic, social and also ethical expectations of their work. The pedagogical approach adopted at Manchester is aligned with the principles and frameworks of Education for Sustainable Development (ESD) which, according to Wals (2014), provides a transformative approach to education encouraging the adoption of sustainable development (SD) principles, ethics and values.

Bearing this in mind, where does Education for the Circular Economy (ECE) leave the last decade of Education for Sustainable Development (ESD)? Is ESD so 'last season' and ECE the new 'must have' in the higher education (HE) engineering curriculum? *Or* can ESD and ECE complement each other in order to educate better prepared 'future builders'? And if so, how does this 'partnership' between ESD and ECE could be introduced in practice within the HE curriculum for engineers?

It could be argued that to some extent, core principles of the CE as well as the pedagogy suggested by Webster (2013) and the EMF (2014) have already been making their way into the HE curriculum for several years now. This paper examines how the approach developed, and still developing, towards issues of educating engineers for global societal responsibility and sustainable development (SD) lends itself well to the embedding of ideas brought together under the heading of CE. This paper primarily focusses a specific module, Interdisciplinary Sustainable Development (ISD), an elective module for year 3 undergraduates available to students from any discipline (engineering, science and humanities) studying at the University of Manchester. Details of course content and structure, projects used, course delivery methodology, assessment and analysis of students learning outcomes are discussed. A brief summary of the challenges and lessons learnt when implement the same pedagogy in other modules is briefly discussed at the end of the paper.

## 2 Theoretical background

The CE is not a new concept. It builds on a variety of "schools of thoughts" related to, for example, industrial ecology (Graedel and Allengy, 1995), product life and the substitution of products for services (Stahel, 1997) and cradle-to-cradle approaches, where waste becomes 'food' and, subsequently, a value-producing resource (McDonough *et al.*, 2003). Sauve *et al.* (2016), argues that the novelty is due to the momentum that the concept is gaining among business practitioners, policy advocates and educators, such Ken Webster from the EMF. Sauve provides a comprehensive overview of the concepts of environmental sciences, SD and CE, how these are linked to each other and the implications for trans-disciplinary research. Overview which the authors believe is of interest within an educational context. Sauve reports that SD has core principles focused on societal good whilst the CE core principles are focused on models of consumption and production. One of the criticisms of the CE is the lack of social focus (REF). Although, CE advocates and policy makers (EC, 2015) claim that social good and increase quality of life will be a consequence of a CE, hence CE becomes a tool for SD. This raises some concerns from an educational perspective, particularly in engineering education, because the social perspective has been recognised as 'lacking' in engineering education and recent efforts have been made to address that 'gap' (Leydens *et al.*, 2014) in order to better equip engineers to fulfil current very broad expectations of their profession including environmental, economic, social and ethical considerations.

On the other hand, a criticism of SD is how poorly dealt with economics, despite being a "pillar" of SD (Webster 2013). Furthermore, some scholars report that, from an environmental perspective, the past focus of SD has been on waste reduction, recycling and reduction of pollution which are downstream processes of production and consumption part of a 'sustainable linear economy', focus that has also been adopted in the engineering curriculum (Sauve *et al.* , 2016). It could be argued that there is some true in that. However, more recent literature in the area of engineering education for SD (or sustainability) provides inspiring examples of university modules *implicitly* exposing students to some of the core principles associated with the CE, principles such as 'system thinking', reduction of raw resource use to optimise the use of by-products, waste as 'food', extended product life (design for repair, dissemble, etc), incentivise the reintegration of post-consumption products in the manufacturing process, collaboration, shared value, transition from service to product, etc. (EMF, 2012). The following examples illustrate how some of those principles have been introduced in the engineering curriculum using active collaborative learning pedagogies. Claesson and Svanström (2015) report the importance of 'system thinking' and 'wicked' problems in engineering education and share their experiences developing *'system thinking'* in engineering education for sustainable development. Lee (2015) discusses the incorporation of system-based life cycle thinking and sustainability in engineering curricula as a means to broaden the thinking of thinking of sustainability for engineering education beyond purely environmental considerations. Life Cycle Assessment, economic considerations, sustainability as a source of innovation and 'learning by doing' are key elements discussed by Lee. Moon (2015) reports a new elective module in sustainable manufacturing delivered by the Department of Mechanical and Aerospace Engineering at Syracuse University open to any discipline campus-wide. The module aims to emphasise that sustainable manufacturing is key to tackle global sustainability issues. It provides a view of manufacturing which requires a holistic approach to a complete product lifecycle while considering the impacts of each decision made in each phase of the manufacturing activity on sustainability. A case-based module on urban water systems was developed by Flynn *et al.* (2015) in order to improve students understanding of *stakeholder engagement* processes in the design of complex engineering systems. Active and collaborative teaching approaches within a learning cycle framework are used. It is worth pointing out that, most of the modules outlined in this review did embed explicitly or implicitly 'business/economic' concepts such as innovation, entrepreneurship and business models within a sustainability context. For example, Moon's module (2015) includes lectures on 'sustainability in business' and 'social entrepreneurship', linking sustainability to business and social good. It seems that nowadays students are being educated and encouraged not only to think about waste reduction, using renewable energy, etc. but also to think and put into practice more 'circular' way.

## 3 Interdisciplinary Sustainable Development: Module Structure and Implementation

### *3.1 Background*

Interdisciplinary Sustainable Development (ISD) is an elective module for year 3 undergraduate students that has been offered for several years. The starting point of this work was an action research project sponsored by the Royal Academy of Engineering that took place in 2008. The project concerned the embedding interdisciplinary experiential SD education within the curriculum to develop undergraduate students' skills in understanding change processes and some of the skills involved in change management, in an inter-professional context. The student cohort, initially engineering students (Mechanical, Civil and Electrical and Electronic) and environmental sciences students, were exposed not simply to environmental sustainability but also to social and economic issues and objectives embedded within the SD concept. In addition to that, core to the project was the use of a contextual, active, multidisciplinary, collaborative and cumulative approach to learning using problem based learning (PBL) and 'wicked' open-ended projects. It's worth pointing out that within the context of this work, PBL is not about *problem-solving* since SD (and the circular economy) presents very complex 'problems' which do not have a 'right' answer, therefore not solvable. After exploring the use of the term *dilemma-based learning* instead the authors reverted to use the term PBL which in this work is used in the sense of not straight forwards complex scenarios ('problems') that must be investigated, leading to new strategies being proposed that must be justified by the teams that created them. Background work for this work and terminology used has already been extensively reported elsewhere (Tomkinson *et al.*, 2008; Dobson *et al.*, 2012; Tomkinson *et al.*, 2016).

The work presented here focusses on ISD module, since 2012, an elective module open to year 3 undergraduate students from *any* discipline studying at the University of Manchester but Electrical and Electronic Engineers (EEE) who since 2012 have a bespoke compulsory SD module. In the last 4 years, ISD cohort size has varied between 43-55 students. Although the module is very popular among engineering students the overall the cohort is a good mix of students from the following disciplines: Civil and mechanical engineering, Physics, Biology, Chemistry, Maths with Finance, Computer Sciences, Environmental Sciences, Economics, Modern Languages with Business and Management and Politics and Modern History. The module is delivered through the Manchester Enterprise Centre, a teaching centre based at the Alliance Manchester Business School. It's worth mentioning that most teaching staff delivering SD modules has an engineering or scientific background.

The specific learning outcomes in this unit are prescribed as:

- demonstrate an understanding of the challenges associated with implementing changes for sustainable development, in a 'real world' scenario.
- apply a non-bias, holistic and systemic approach to investigating complex, multi-criteria, open-ended issues that incorporate uncertainty and conflict of interests
- work across traditional disciplinary boundaries in order to develop innovative strategies and credible proposals implementing principles of SD.
- apply reflective practice to engage in continuing self-improvement in a professional context

Through tackling two summatively assessed short multidisciplinary team projects based on topical, real-life scenarios, students gain understanding of the complex issues surrounding development towards social responsibility, environmental and economic sustainability, including a transition towards the CE. Individual contributions to the team are also evaluated through a peer-evaluation. Individual development throughout the unit is demonstrated in a summatively assessed individual reflective report, where students review, reflect on and then develop action points for themselves in an iterative cycle as a preparation for future continuing professional development.

### *3.2 ISD: Course content and structure*

The module has a much emphasis in knowledge and understanding of principles for SD and the CE, as it does in the development *of* skills and competences to influence change towards SD and the CE. Main course topics and structure are summarised in Figure 1 and explained in this section.

| Wk | Lecture/Team Activity | Team Project 1 | Team Project 2 |
|---|---|---|---|
| 1 | Introduction to the course<br>Introduction to Sustainable Development: What? Why? | | |
| 2 | Towards Sustainable Development: How?<br>Basic Frameworks and Tools | | |
| 3 | Introduction to the Circular Economy: What? Why? How?<br>Activity A: Speed meeting | Briefing, analysis, allocation of tasks | |
| 4 | Information Literacy Skills<br>Activity B: Setting ground rules | Discussion and allocation of tasks | |
| 5 | Activity C: Project Management<br>Project 1 Client Q&As | Discussion and allocation of tasks | |
| 6 | Effective Teams, Leadership, Creativity & Innovation<br>Activity D: Mixed Teams | Submit Project 1 report | |
| 7 | Activity E: Team Process Review | Receive Project 1 report feedback | Briefing, analysis, allocation of tasks |
| 8 | Reflective practice<br>Activity F: Reflective practice | | Discussion and allocation of tasks |
| 9 | Project 2 Client Q&As | | Discussion and allocation of tasks |
| 10 | Activity G: Effective presentations | | Discussion and allocation of tasks |
| 11 | Assessed Team Project 2 presentations | | Submit Project 2 report |
| 12 | Activity E: Team Process Review<br>Peer Assessment | Receive Project 2 presentation feedback | |

Figure 1: Current module topics and structure

#### 3.2.1. Course structure and schedule

The delivery of ISD encompasses a series of interactive lectures and team activates. The course starts with a series of interactive lectures to motivate and equip students with the necessary background that is to be applied in their team projects. Weeks 3-12, students work in multidisciplinary 'consultancy' teams of 4-6 students. 2 hours each week over a 12 weeks period constitutes 'class time'. Being a PBL module, 'class time' is mostly used for facilitated team discussions to tackle activities A-E and discuss research done 'outside the classroom' to advance the team project. These 'in class' activities are designed for students to develop communication, negotiation, information research and literacy, multi-criteria decision-making, project management and team working skills. 'Class time' is not used to conduct research for the project. The team project execution process has been described elsewhere (Dobson and Tomkinson, 2012). Each team project lasts for 3-4 weeks. When possible, each team has an opportunity to attend a short Q&As session with the 'client' who has devised the project. This session is highly regarded by students because provides them with an opportunity to meet someone working in 'the real world' trying to solve a 'real world problem' a key factor for students to enrol in this module as shown in student feedback. Feedback from project 1 is combined with a team review session before project 2 starts. This provides students with an opportunity to improve both the team performance as well as the quality the deliverables expected in project 2. Week 11 is used for project 2 team presentations. Feedback and a final team process review take place in week 12. Students are expected to submit their individual reflective report the last day of term.

3.2.2. Lectures

Topics explicitly covered in the current module include: roots to unsustainability, introduction to sustainable development, 'System thinking': cradle-to-cradle, Life Cycle Assessment (LCA), sustainability reporting, sustainability and the Enterprise, from the linear economy to the circular economy, stakeholders' analysis and engagement mechanisms, and, corporate social responsibility and shared value. Since 2008, all those topics have been core to ISD and other SD modules at Manchester although some such as shared value "what is good for society is good for business" developed by Harvard professor Michel E. Porters (Porters and Kramer, 2011) and the CE were not *explicitly* covered in lectures until 2015 and 2016, respectively, in an attempt to keep the course 'fresh' and equip students with the most up to date concepts and terminology used in a professional context.

Lectures only provide an introduction to SD and CE. Students are expected to further their knowledge using the resources provided and their own research based on their previous discipline knowledge and learning needs. Extensive on-line resources (e-books, links to websites, videos, case studies, etc) complement lectures.

3.2.3. Student Team Projects

'Wicked' project selection and project brief design has been discussed elsewhere (Dobson and Tomkinson, 2012). Most projects are related to technology and social innovation. Where possible, projects are 'live' and are drawn from real life, championed by an external expert or a practitioner at the University who acts a 'client'. Working as a consultancy team students are required to provide the client with a reasoned, credible, innovative and implementable strategy which integrates and balances the environmental, economic, social and ethical aspects of the project.

In carrying out those projects, students are required to consider, among others:

- Customer and end-user needs
- Adoption of alternative energy sources and/or sustainable materials
- Design for sustainability, recycle, re-use, dissemble, etc.
- How waste could be utilised elsewhere
- Justification of lifecycle costs
- Use of a life cycle assessment to systematically understand the impact of each decision to minimise or eliminate trade-offs
- Innovative business models (social enterprise, sharing economy)
- The social and ethical implications of their chosen strategies

Projects usually vary every year. Examples of the two projects used in 2016 are as follows:

- Project 1: 'Alcohol-powered cars: a sustainable strategy for UK car manufacturers? How? Or, what else then?' The client: a UK car manufacturer under pressure to comply with strict EU car emission regulations looking at future-proofing the business.
- Project 2: '3D Printing the future'. The client: Techfortrade, a UK based charity working with local entrepreneurs to test innovative approaches for building sustainable and replicable businesses that use the power of emerging technologies to facilitate trade (economic development) and alleviate poverty. With £10K to donate and 6 potential 3D printing related projects to fund, students were tasked with justifying which project to fund and propose an implementable strategy to make the project sustainable. This added a 'twist' and healthy competition to the module as students were pitching for the funding.

The nature of the project 2 resulted in a variety of 3D printing projects being presented in week 10. Some teams did chose the same project to be funded resulting in a variety of strategies for the same project. Each team presented to a panel of academics, the client and also to the other teams. Anyone in the audience was encouraged to ask questions. This 'open' session was highly regarded by students as provides them with an opportunity to learn how other teams have approached the same project brief and even the same project chosen to be funded. The session ended up being highly interactive with students doing most of the questioning challenging their peers and even providing feedback on how the presented strategy could be improved.

## 4 Discussion

Based Most project 1 team reports for the 2016 cohort were found to be rather bias towards environmental and, to some extent, economic considerations. Students struggled with the social dimension of the project. This has been a trend since the beginning of the unit. Several reasons for this: although the cohort is multidisciplinary, over 50% of the team members are engineers which usually have previous knowledge of environmental sustainability and possibly influence the direction of the project. The bias towards economic considerations has already being a trend for years. This tends to be because most 'business knowledge' that student have prior to taking this module is linked to the 'linear economic' model. Feedback for project 1 results in a considerable improvement in the quality of project 2 deliverables. This has also being a trend for this module which is designed for cumulative learning and continuous improvement. It's been noticed that more multidisciplinary teams tend to produce better quality deliverables. In the past, this has also been pointed out in the unit evaluation questionnaire administered to students. Some students claimed feeling at 'disadvantage' by working in 'less multidisciplinary' teams. Unfortunately, there are institutional barriers that stop this module from being truly multidisciplinary as there is no limit to the number of engineers than can take this module. However, in recent years this module has become more popular among none engineering students and will perhaps allow for more multidisciplinary teams in the future.

To benchmark the impact of introducing the concept of the CE the same project 2 was used in 2015, prior to the explicit introduction of the CE and, in 2016, upon explicit introduction of the CE. A survey carried out in week 1 2016 revealed that 71% of students had previous knowledge of sustainable development. However, only 33% of students have heard of the CE but weren't sure what it meant and the remaining 67% of students have never heard of it. From an academic perspective the explicit introduction of the concept of the CE made no noticeable difference to the nature and quality of the strategies produced by students for project 2. This may be because prior to 2016 many of the concepts brought together under the heading of CE were already embedded in the module one way or another. In the past student feedback has been very positive for every aspect of the module: delivery, learning experience, relevance to the real world, potential to enhance employability skills, enjoyable module, etc. In 2016, feedback scores have remained equally positive upon the explicit introduction of the CE which is encouraging since, in the past, in other modules we have encountered some resistance by engineering students when exposed to the wider aspects of sustainability (other than environmental) which students perceived as 'too much business, nothing to do with engineering". It could be argued that, in 2016, nothing 'new' in terms of 'how?' was introduced to students. The novelty perhaps was the 'what?' meaning the 'new' terminology introduced in lectures. Students seem to have positively reacted to the introduction of this 'new' concept. After the lecture in week 3 introducing the CE, two engineering students e-mailed the unit leader asking for further information about the CE and one stated: "I cannot understand why throughout my degree I have never been told about this [the CE] before". An open feedback discussion took place in week 12. A few students pointed out that they would have liked to hear more of business models for a CE. As an academic delivering sustainable development modules, concerns regarding the lack of 'social focus' in engineering education and also a criticism of the CE, it was encouraging to find in most students reflective reports a good balance of learning about environmental protection, economic growth but doing in an ethical manner without compromising societal good. It's worth pointing out that project 2 had a key role on this outcome as it is a good example of projects in which waste can be turned into wealth for those who really need it whilst protecting the environment. A large part of the cohort is international students returning home after graduation. In many reflective reports they have highlighted the invaluable learning that particular project gave them, knowledge and skills that they plan to apply at home. One particular student from Jordan is seeking government funding to implement the project 2 she researched during this module.

## 5 Conclusions and on-going work

The pedagogical approach to ESD well established in Manchester to embrace wider concepts of sustainability (environmental, economic, social and ethical) within a multidisciplinary, contextualised, active and feedback rich learning environment has been illustrated here with a specific module, ISD. Approach which has lent itself well to the embedding of ideas brought together under the heading of CE. The explicit introduction of the concept of the CE made no difference to quality of the discussion or the deliverables produced by students. Past years deliverables already showed a 'circular way of thinking'. However, student feedback suggests that students, including engineers, are willing to learn more *about* and *for* an economy that is increasing gaining momentum. Discussion whether to change the current module title and adjust the learning outcomes to reflect the explicit introduction of the CE in this module are on-going. Learning from feedback is key to this module and, as discussed in the introduction, to ECE. It's worth mentioning that the rapid turnaround of project feedback it is only possible because of the small cohort size and some modifications to the delivery approach have been adopted when delivering similar modules to much larger cohorts. Regardless of future changes to modules tittles and slight modification to course content, to date, the pedagogical approach at the University of Manchester suggests to be preparing engineering students to appreciate the complex situations they will encounter in the future and equip them with knowledge, skills and attitudes to accelerate the transition towards SD and, we do argue, the CE.

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# Circular economy in engineering education: a disciplinary approach to an interdisciplinary challenge

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## Abstract

Circular economy is an intrinsically interdisciplinary challenge, since typically circular economy technologies and business models are based on collaboration within engineering, economics, governance, ... Hence, when educating future students, the challenge will be to ease the transition for the students who are accustomed to a mainly disciplinary context, and give them the skills and knowledge to cope with the interdisciplinary nature of circular economy---a true interdisciplinary challenge. The case for engineering students is presented here.

Since 2014, a new course "sustainable materials management", covering the field of circular economy, has been introduced in the materials engineering masters at KU Leuven. The need for such a specific course, in addition to sustainability in the traditional course set, was clearly expressed by the industrial board and by the students. The course starts with the engineering paradigms the students know already, which enhances the appropriateness of their disciplinary knowledge for the field of circular economy, while at the same time broadens their views on the systemic level and sub disciplines such as ecological economics and environmental sciences. This (course) fits perfectly within the overall "disciplinary future self" education vision of KU Leuven and is essential for forming engaged engineers. The course not only is a course on sustainability, giving insight in circular economy and the sustainability concepts behind it, but also a course for sustainability, providing the students the tools for creating and evaluating their own circular technologies and business models and implementing these tools on the research they do on their master's theses.

The paper covers the rationale behind the course, the learning objectives, the approach with the disciplinary and interdisciplinary aspects and nexus, the alternative learning tools used, as well as the future steps, amongst others the introduction of a MOOC the author has created on e-waste together with EIT Climate and UNEP as part of the assignment within the course. The paper also frames this particular course within the overall university vision. Students have evaluated and commented on the course very positively, pointing at the systemic thinking approach, the direct relevance for their future jobs and the motivation to tackle circular economy challenges.

## 1 Introduction

It cannot be denied that circular economy gets exponential attention from policy makers, governmental agencies, companies and NGOs. Some already call it a hype (see e.g. the vice president of Veolia North America (Pinero, 2016)). Many reports have been issued by the EC (European Commission, 2015) and by Ellen McArthur foundation (Ellen MacArthur Foundation, 2012), the EEA (European Environmental Agency, 2016), etc. However, all this attention is in stark contrast with the (lack of) academic literature on the subject of circular economy. Unquestionably , there is a lot of literature on the underlying principles, such as industrial symbiosis, materials flows, sustainable production and consumption, and sustainable materials management. Nevertheless, scientific circular economy research seems to be at its infancy. Accordingly, courses on circular economy are today scarce too.

Education's first aim is to prepare and help mould students into their future selves. Many companies recruiting engineers are very much aware of the need for engaged students. A Belgian company, Umicore, active in circular economy (Campforts, Meskers, & Van Camp, 2011) states: "*Through education on sustainability-related topics people are made aware of the scale of the global challenges, encouraged to take up the challenge to solve these issues from a personal engagement and provided with the (engineering) tools to do so. (...) People with the appropriate competences and mindset are required to tackle the issues in the sustainability field*." This underscores the idea that students become more aware of the day to day industrial and societal issues when taught sustainably related subjects. This also supports the view that graduates of sustainability courses can have a profound impact because they have the knowledge and the tools at hand to tackle both societal and industrial issues.

It is clear there is a need for sustainability courses in order to introduce science and business minded graduates who have a pulse on societal issues into the work force.. How to realize education for sustainable development (ESD) is another question. The UN Decade on Education for Sustainable Development (UNESCO (United Nations Educational Scientific and Cultural Organization), 2007) and more recently the Global Action Programme on Education for Sustainable Development as follow-up to the United Nations Decade of Education for Sustainable Development after 2014 (UNESCO (United Nations Educational Scientific and Cultural Organization), 2013) provide instructions for universities on how to revise their curriculum to put emphasis on sustainability issues (Hegarty, Thomas, Kriewaldt, Holdsworth, & Bekessy, 2011). The principles 5a and 5b put forward by the Global Action Programme form the basics of the here described course and summarize very well what courses within ESD are about. Sterling points additionally to the characteristics of a sustainable world, being change, uncertainty, risk and complexity, for which sustainable education should student prepare (Sterling, 2013).

The best way to embed sustainability studies into higher education has been the subject of many studies (Roorda & van Son, 2016). The presently described course is a modest step in what should be a university-wide incorporation of sustainability in courses, programs, curricula and finally, it requires nothing less than a transformation in the organizational cultures of universities (Moore, 2005). While this process of integration of ESD at the higher education level will be slow and tedious, some stand-alone courses in dedicated fields where momentum for change already exists should be encouraged, not only because they can be quickly developed and executed , but also because they foster crucial, transferable skills with a focus on applied professional contexts (Hegarty et al., 2011). They seek to locate new knowledge within disciplinary spheres and situate their learning objectives in complex, real-world contexts (Hegarty et al., 2011). Hence it is believed stand-alone courses add value to the ESD goals.

## 2 The context of the course "sustainable materials management"

In 2015, a course "sustainable materials management" was introduced at the department of Materials Engineering of KU Leuven in the curriculum for materials engineers, at the very end of their studies. It is one of the core courses in the 2nd year master. Before diving into the learning objectives, and presenting an evaluation and discussion, this paragraph explains what the rationale was for introducing the course and how it relates to the faculty and university mission on education.

## 2.1 Rationale of the course

The first reason why our department started to introduce a new course on sustainable materials management, was the future supply of materials and their impact on the environment. It is a characteristic of materials which material engineers should be well aware of in their job. This does not only encompass resource issues (absolute, economic and structural scarcity), but also awareness of strategies to produce and use (and reuse) materials more efficiently and with less impact, and how to keep their value in the economy as long as possible. A materials engineer will need to be an expert in these issues, next to his/her traditional role of understanding of the interconnectedness between materials properties, structure and processing. This need to be knowledgeable in circular economy will ever increase the coming decades.

There is also an external incentive for educating materials engineers in the circular economy. As shown in the introduction, there is clear societal need and trend to move towards more circular business models and material value chains. The ability to prove a project contributes to circular economy, will not only be an asset, but it will also be a strict requirement to attract investments in new industrial projects, or to attract research and innovation funding. OEMs, such as Ikea, already today request their suppliers to demonstrate that their goods are resourced sustainably.

Thirdly, the topic of sustainable materials management and circular economy is a growing research field within the university. Thus, research-based education should pivot toward new research directions. The course can be seen as a direct result of the research within the policy research centre sustainable materials management for the Flemish government, and of the research within the research line "sustainable materials management'" (SIM²) of KU Leuven. It will be further aligned with research that is started up in the framework of EIT RawMaterials.

Fourthly, the academic staff of the department felt a need to have a separate course on sustainability assessment and aspects of material in order to give students an comprehensive view on this topic, including assessment methodologies (which are not introduced in other courses) and strategies covering the entire materials life cycle (mining – production – use – end-of-life – recycling) and material families (metals – ceramics – glasses - polymers – elastomers – hybrids). The need to cover all material families in one sustainability course can be justified. For example, in the case of recycling by the (new and necessary) evolution to use a product-centric approach for optimizing recycling value chains (Reuter & Van Schaik, 2012), in which an optimal and integrated solution has to be designed for all materials present in a product, and not only for the highest volume materials (as is often the case).

Finally, the course was intended to draw from the experiences and thought processes already formed by these materials engineers-to-be. The course clearly starts from the engineering paradigms the students know already and deepens the applicability of their disciplinary knowledge for the field of circular economy, while at the same time broadens their view towards the systemic level and disciplines such as ecological economics and environmental sciences.

## 2.2 Vision of the university

The KU Leuven vision on education (KU Leuven, 2014) is centred around the "disciplinary future self" of students. Ideally, students will have a vision of what they would like to do when finished their studies, what function they would like to have in society. (Erikson, 2007) describes 'future selves' as: '*Possible selves are conceptions of our selves in the future, including, at least to some degree, an experience of being an agent in a future situation. Possible selves get vital parts of their meaning in interplay with the self-concept, which they in turn moderate, as well as from their social and cultural* *context.*' It is clear that this context, as described in the introduction, is very much aware of the finite resources humankind has remaining, and concepts such as circular economy are very inspiring and attract widespread attention. Also students become more and more aware of sustainability issues – initiatives such as "days without meat"-- are very popular at the university. Putting ore focus on the ability of engineers to design sustainable solutions for a finite planet, would probably also attract students with a different view on their "future self" than the traditional technology-focused engineering student. This is a conclusion of WPI (Apelian, 2010) after introducing a "grand challenges" course on sustainable development.

The vision of KU Leuven put forward a "disciplinary" future self, i.e. students choose a certain educational curriculum (engineering, law, medicine,…) to give shape to this future self. The curriculum helps to cope with their future societal responsibility, gives the necessary tools for it. It does not mean that the curriculum in itself cannot be interdisciplinary. The course presented in this paper is fully embedded in the curriculum of a materials engineer (hence, disciplinary) and the way of thinking engineering students have acquired, but at the same time broadens this to other disciplines which all together are needed to understand the complexity of sustainability.

The Faculty of Engineering states that its mission is to educate high-quality engineers for the benefit of society, "*which entails preparing students for the world of tomorrow where societal, environmental and human dimensions play an important role due to the advent of complex technical and societal challenges that require a multidisciplinary approach.*" (Faculty of Engineering Science, 2016) The faculty mission refers more explicitly to two complementary elements of the future self, i.e. "Bildung" and "Beruf", where "Bildung" consists of the development of values, culture and citizenship and "Beruf" focuses on the development of entrepreneurship, professional and leadership skills. It is clear that the focus of the here presented course is more on the "Bildung" aspect, though starting from a "Beruf" background.

With respect to the position of sustainability within the education of the university, the sustainability council has issued a complementary guideline. The concern of the council is that a better understanding of sustainability as structuring perspective with respect to the interlinked ecological, social, political, financial and human crises be construed as more than urgent. This would require a renewed transdisciplinary and system-oriented approach of scientific research and academic education. It is a crucial social responsibility of the university to train students in transdisciplinary collaboration, in order to cope with the sustainability challenges of the future. On the one hand, there is the need for "education on sustainability", in which the focus lays on the disciplinary know-how to unravel, qualify and quantify, and monitor sustainability issues. On the other hand, there is "education for sustainability", with focus on didactics and methodologies to include a systems approach of the reality in all kind of courses, in order to support an education oriented towards the development of a sustainable future. Both education on and for sustainability are needed to enable students in their future jobs to elaborate specific technological, social, economic, political solutions for a more sustainable society. The here discussed course is catalogued as and given as an example of a course on sustainability, giving insight in circular economy and the sustainability concepts behind it, but it also is a course for sustainability, providing the students the tools for creating and evaluating their own circular technologies and business models and implementing these tools on the research they do in their master's theses.

## *2.3 Industrial advisory board*

The department installed five years ago an industrial advisory board to discuss future changes and points of attention in the materials engineering bachelor and master program. The advisory board is composed of 15+ representatives of major materials industry companies in Belgium, all of whom are engineers,but not necessarily alumni of KU Leuven. In addition, there are also some representatives of research institutes and governmental agencies, in order to reflect accurately the career options of our students. The rationale for and outline of the content of the new course has been presented to this industrial advisory board. The conclusion was unanimously positive: the board recommended strongly the introduction of the course in the curriculum of materials engineers. The content was even considered as essential for future materials engineers. A dedicated course on sustainability of materials and material life cycles gives, according to the board, the advantage to deepen the understanding of causes of resource risks and possible strategies to tackle it , while also acquiring methodologies to quantify and discuss with rational (and critical) arguments on resource efficiency and the environmental impact of materials. A suggestion was also to include ethics, consumer perspectives and health issues in the course. Finally the board recommended the course to be part of the core courses, and not as an elective one. The positive attitude of the industrial advisory board was helpful in the final decision to introduce the course in the curriculum. Without a clear interest of the partner companies in the industrial advisory board, the course would probably not have been accepted.

## 3 Learning outcomes and materialization

### *3.1 General learning outcomes*

Based on the rationale of the course and KU Leuven vision on sustainable education, 5 general learning outcomes have been formulated. They are also inspired by the desired student attributes as a result of sustainability education put forward by the University of British Columbia (UBC, 2011).

1. *System thinking*

To understand the complex environment in which materials, products, processes and systems are embedded, the interlinkages between all phases within a materials life cycle and the interaction with the (natural, social, economic, political) environment and to demonstrate the insight that actions at one place in the system has consequences within, between and among systems.

2. *Critical knowledge on sustainability frameworks*

Acquire the knowledge of different sustainability models and paradigms, and the way to further study them (where possible with quantifiable outcomes) and demonstrate critical reflection and analytical thinking with the focus on applying learning to practical solutions.

3. *Integrative skill*

Appreciate that studying sustainability and engineering future sustainable solutions requires input and collaboration from many different disciplines (interdisciplinarity) and from society (transdisciplinarity).

4. *Translate disciplinary knowledge to a sustainability framework*

Use and translate the profound disciplinary background and engineering paradigms the students know and deepens the applicability of their disciplinary knowledge of the field of circular economy

5. *Prospective thinking about engineering developments*

The ability to oversee the consequences and the opportunities of engineering developments for the society and the planet.

### *3.2 Specific learning outcomes, content and evaluation*

The general learning outcomes have been translated into more specific outcomes related to the specific context of circular economy and the possible role of materials engineers in that field.

1. The student understands material circles, product cycles and material flows and recognizes bottlenecks in the current use of materials from a general perspective of sustainability.
2. The student is able to quantify material efficiency (resource efficiency) and sustainability of materials (environmental impact), using MFA and LCA environmental methods. Can interpret results and assess the accuracy of such analyses by understanding the statistics of such methods.
3. The students acquires some knowledge of economic and social impacts of material life cycles and the basic discourse on circular economy provided by other disciplines. He has some knowledge of methods such as LCC, LCSA, CBA, EIA, IO analysis.
4. The student understands the different models and systems to close material cycles and can propose (technological) solutions for specific material and product cycles.
5. To know about new developments and policies for sustainable use of materials, such as the materials decree, chemical leasing, urban mining, .. and some case studies (eg materials for solar energy) demonstrating future developments and possible sustainable strategies.

These specific learning outcomes are translated in the different modules of the course, which can be summarizes in the following building blocks of the course:

a. What is sustainable materials management and circular economy? In this part of the course, sustainability and the role of materials, industrial ecology (including major impacts, resource extraction and stocks, sustainability concepts, reduction targets) are taught as general framework. Also the building blocks of sustainable materials management, comprising material flows, material life cycles and metabolism, strategies and technologies for circular economy are discussed.

b. Quantification methods and indicators for sustainability of material cycles. This part includes a thorough discussion of Life Cycle Assessments including exercises, and the possibilities, drawbacks of LCAs, data sources, uncertainties. Other methods discussed are: materials flow analysis, environmental LCC, exergy, I/O analysis, EIA, LCSA.

c. Implementation of sustainable material management and circular economy. A framework is given to evaluate, optimize and rethink technologies and business models for circular economy. Several case studies are discussed, such as landfill mining, WEEE and electronics recycling,… The link to resource economics (with a specific module on this aspect) and the legal framework is made.

d. The most important part is a study students make themselves to evaluate a certain product, process or system on its sustainability aspects and to propose improvements or alternatives in order to deliver the same function in a more sustainable way. They use the GaBi education software for setting up a LCA of their subject, which is very instructive to understand the system and the interaction with other systems. They basically have to write a paper (re-trace, re-think, re-imagine the subject of their study) describing the sustainability context of their subject (be it a new material, process or system), the sustainability assessment (LCA, with link to other possible assessments) and discussion on bottlenecks, possible pathways to improve the sustainability and framing it in the economic and legal context. It is recommended to the students to take the material, product or process they study during their master's thesis, so that there is a clear link and deep knowledge of the subject already. This part is very interactive between the students and members of the research group.

The evaluation of the course is based on the paper and a thorough discussion of the paper. In that discussion, the 5 learning outcomes are tested. Critical thinking, understanding of the subject, ability to link the subject with the broader sustainability framework, … are included in the evaluation.

### *3.3 A MOOC on the e-waste challenge*

In the coming years, the students will have the opportunity to follow the MOOC "the e-waste challenge" and performing the final assignment of this MOOC as alternative for the paper (part d of the course). This MOOC has been built by EIT Climate and UNEP, with the support of WRF, KU Leuven and EIT RawMaterials, and its content and learning outcomes are very much aligned with the course described in this paper. The overall aim of the MOOC is to "bring together students, policy makers and recycling operators from around the world to raise awareness, to educate and to galvanise action around sustainable opportunities to recover and recycle e-waste that will minimise GHG emissions and protect human health and the environment." The MOOC is attractive to be included in the course, not only because of the relevant subject, but also since it adds some practical skills and learning outcomes. The MOOC is very interactive, with small pieces of information (but with links to a large library of documentation) and videos and offers many possibilities to interact: via reflective learning, (activities in a learning journal, blog, …), co-constructive learning (discussion groups and task teams) and dialogic or peer-to-peer learning. The learning is action-focused, through individual and team-based 'learning by doing', and aims at rendering the learners an entrepreneurial mind-set to solve real-world sustainability problems of e-waste material recovery and recycling.

## 4 Discussion

We will now compare the materialization of the described course with the general outcomes that have been put forward. Although system thinking should be part of every engineering education, one of the students remarked in his evaluation questionnaire of the course, that for the first time he had to use system level thinking. This was remarkable, since the term "system thinking" is never communicated to the students during the course, nor is written in the syllabus. Indeed, the way of looking at materials/product/system cycles and their interaction with the environment by a.o. materials flow analysis and life cycle assessments, is very much in line with systems thinking as defined e.g. by (Arnold & Wade, 2015). Much attention is also going into the students strengthening their ability to think critically. For instance, by including discussions on uncertainty, risk and complexity, in their final paper. Interdisciplinarity is guaranteed by including modules from economics (given by a guest professor) and cultural theory. However, social aspects are not yet fully integrated, which is one of the drivers to make the e-waste challenge MOOC as an (elective) part of the course. The MOOC adds the dimensions of transdisciplinarity to the course. Finally, by electing to write a paper on a topic related to the master thesis, the students learn to translate and test the background they have built up in a typical engineering study to a circular economy framework. Interestingly they are very much challenged to learn the consequences and the opportunities of the engineering development they have been themselves active in for the past 10 months. This linkage between thesis work and sustainable materials management paper brings the sustainability thinking very close to the student's daily activities. Sometimes it gives very surprising perspectives. As a result, several students starting a PhD after having followed this course, are also including a sustainability evaluation work package in their PhD work.

The course is a stand-alone course of only 3 ECTS. The choice has been to focus on the above described learning outcomes, which means that an outcome on acting for positive change (UBC, 2011) is not included here. In this paper, the competences for sustainable development (e.g. as described by Lambrechts (Lambrechts, 2012) and Roorda (Roorda, 2010)) are not explicitly covered. Implicitly, these competences have a place in the course, but they should be complemented by other courses and be frames in the entire educational programme.

## 5 Conclusions

The here described course is stand-alone and provides a reflective perspective on the acquired disciplinary knowledge of engineers. Its added value is that it is well embedded in the engineering framework which the students are well accustomed and at the same time, opens up these frameworks to sustainability issues. A stand-alone course that is given as introductory course in the first year of an educational programme is a valuable alternative (Apelian, 2010; Hegarty et al., 2011) and can give the fundamental knowledge to build upon in other disciplinary courses later on. The here described reflective course is able to link with the personal master thesis of the students and to integrate and translate disciplinary skills to use them to discuss and cope with the future complexity and uncertainties and to develop a more sustainable future. However, it is quite evident the stand-alone course is not enough to ensure a balanced education for sustainability, it has to be complemented with topical issues within other courses and with a university-wide organizational shift. The course is still too new to be able to evaluate its long term effects, but an indication of its value can be extracted from the students' evaluations of the course, who are the first stakeholders of the course. Students have evaluated and commented on the course very positively, pointing at the systemic thinking approach, the direct relevance for their future jobs and the motivation to tackle circular economy challenges.

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# Engineering education at the heart of the Raw Materials Value Chain

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**Abstract**

EIT Raw Materials has the mission to reinforce Europe's innovation capacity by preparing the entrepreneurs and innovators of tomorrow. By fully integrating the three sides of the knowledge triangle (education, research and industry), the EIT Raw Materials aims at boosting the innovation process: from idea to product; from lab to market and from student to entrepreneur.

A key mission of the EIT Raw Materials is to educate young professionals and specifically engineers by breaking the barriers of classical disciplines. The so-called T-shaped professional will have a strong entrepreneurial mindset and combine an in depth knowledge of his own discipline with a sound understanding of the challenges appearing along the whole raw materials value chain. It is essential that these T-shaped professionals understand their role within the value chain as actors of a more circular economy.

Every educational activity organized under the umbrella of the EIT Raw Materials (RM) Academy will therefore make sure to involve all stakeholders of the raw materials value chain and to contribute to raising awareness with respect to the societal function of raw materials and the related supply and availability challenges.

To achieve these missions and create a long lasting impact, the RM Academy aims to innovate in terms of teaching, which includes:

• The promotion of problem-based learning, self organisation and learning by doing.

• The offer of an open learning environment and a series of online courses.

• Enabling a high degree of mobility of students and professionals.

• Facilitating access to experimental platforms and pilot plants for hands-on training

• Adopting a strong multidisciplinary approach (e.g. joint courses across sectors)

• Thinking beyond boundaries and systematically exploring and generating new ideas

• Transforming innovations into feasible business solutions

• Joint curriculum development

Critical reflection, peer review processes as well as assessments and collegial discussions under the roof of the EIT Raw Material Academy will be used for continuing quality development of the programs.

# 1 Introduction

## *1.1 The European Institute for Innovation and Technology (EIT)*

The European Institute for Innovation and Technology (EIT) is an independent body of the EU set up in 2008 with the aim to foster innovation and entrepreneurship in Europe. EIT is a key player of the H2020 strategy to achieve societal challenges in sectors which are considered as priorities (energy, climate change, ICT, raw materials, health,…). EIT's main mission is to contribute to the competiveness of Europe by promoting and strengthening synergies among businesses, education institutions and research organisations. EIT also aims at creating a favourable environment for world-class innovation and entrepreneurship.

The EIT has adopted an "EIT Quality Assurance and Learning Enhancement Model" (EIT, 2016) which aims at labelling master and doctoral programs contributing to achieve the seven "Overarching Learning Outcomes" (OLO):

1- The ability to identify short and long term future consequences of plans and decisions from an integrated scientific, ethical and intergenerational perspective and to merge this into a solution-focused approach, moving towards a sustainable society.
2- The ability to transform innovations into feasible business solutions.
3- The ability to think beyond boundaries and systematically explore and generate new ideas.
4- The ability to use knowledge, ideas or technologies to create new or significantly improved products, services, processes, policies, new business models or jobs.
5- The ability to use cutting-edge research methods, processes and techniques towards new venture creation and growth and to apply these also in cross-disciplinary teams and contexts.
6- The ability to transform practical experiences into research problems and challenges.
7- The ability of decision-making and leadership, based on a holistic understanding of the contributions of Higher Education, research and business to value creation, in limited sized teams and contexts.

A preliminary requirement for all master and doctoral programs being that they engage a minimum of two academic institutions and two non-academic partners in the development of the curriculum, that they are fully taught in English, that they include a minimum of 30 ECTS mobility and that obey all rules of ECTS recognition.

## *1.2 The Knowledge Innovation Community (EIT Raw Materials)*

In December 2014, a competitive call launched by the EIT ended up in the designation of the knowledge innovation community (KIC) on raw materials. This association (EIT Raw Materials e.V.) with headquarters in Berlin and six colocation centres across Europe gathers sixty core partners (universities, research centres and industries) and about as many associate partners. Interestingly, this extensive consortium emerged during the preparation period from discussions involving both stakeholders of the mining and the advanced materials sectors.

Partners from the mining sector considered this EIT initiative as an opportunity to re-invest into exploration, extraction and mineral processing activities, whereas partners from the materials sector were hoping to support dematerialization, substitution and recycling. It very soon became evident to everyone that there was no alternative to considering the materials value chain as a whole. As a consequence, this KIC initiative was perceived as the perfect shrine for developing innovative research and for creating new business activities aiming at achieving a more circular economy.

## 2 Engineers in a Circular Economy

The EIT Raw Materials selected six themes, which are as many focal points for all education and technology transfer projects to be developed in the future. As shown by fig. 1, all themes have to be perceived as being essential links within a circular value chain. In this perspective, every stakeholder in a project has to know and understand his role in the chain to achieve a more resource efficient Europe.

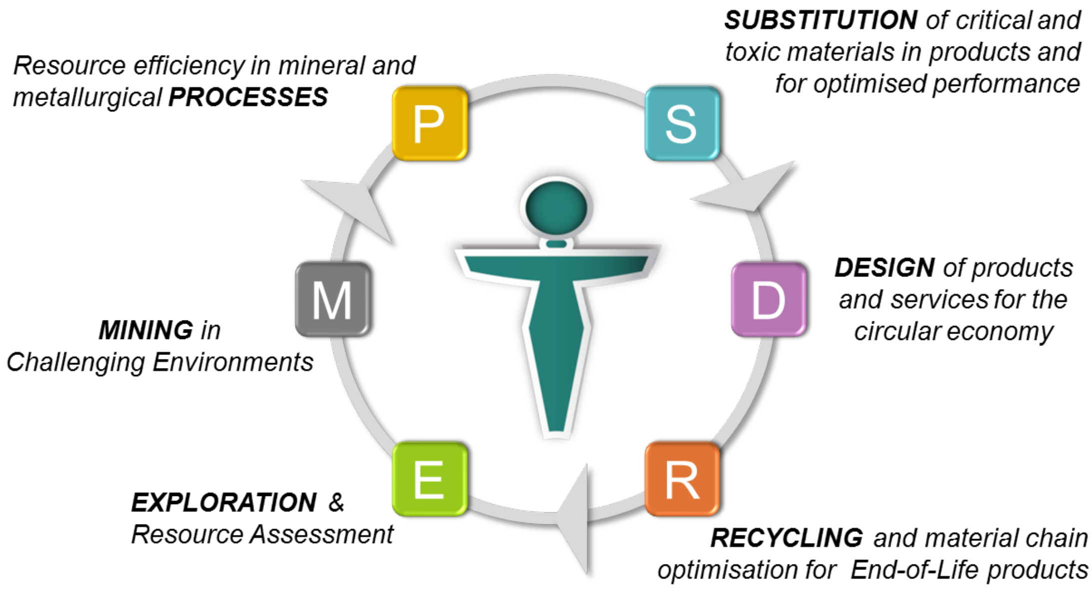


Figure 1. The T-shaped professional and the six themes of the EIT Raw Materials.

This is particularly true for future engineers who will have to understand how any potential innovation contributes to boost the materials loop. This is why the EIT is setting up a raw materials academy ((RM Academy) as an umbrella organisation for all educational activities with the intention to de-silo traditional education and educate T-shaped professionals. In the context of the EIT Raw Materials, T-shaped professionals are "*broad and holistic lifelong learners who combine an in depth knowledge of their own discipline with a sound understanding of the challenges of the raw materials value chain*". Every educational activity organized within the RM Academy should involve a large panel of stakeholders and contribute to raising awareness with respect to the societal function of raw materials. The following sections suggest how existing programs could be redesigned and eventually discusses the need for new initiatives in education.

### *2.1 Georesources Engineering*

Geology is a natural science which is a key knowledge for understanding our environment. Indeed, in the recent decades, many graduates in geology have found a job as environmental experts. However, with regard to raw materials and in the perspective of sustainable development, it is essential to make sure that profesionnal geoscientists also have a good understanding of the extractive industry activities. This is why some engineering schools have long decided to educate georesources engineers. Such engineers have a perfect understanding of the complexity and fragility of our natural environment and know very well that there is no activity without impact on society, economy and environment. They are also well aware that mining will always be a crucial activity to provide our society with the desired materials and that the need for mining is growing as a consequence of the ever increasing world population and the access of a higher number of citizens to better standards of living. Georesources engineers know that our world resources are finite but they also know that many non-geological concepts are hidden in notions such as critical raw materials; strategic resources; scarce metals; etc.

Educating georesources engineers to target sustainable development goals implies that their creativity should be stimulated to adress the following challenges:

- Consider the value of a deposit by taking into account as many possible products and by-products

- Clearly integrate the impact of mining wastes and their possible use (industrial ecology)

- Develop exploration technologies with larger penetration depth

- Include more data into the orebody modelling and regularly update the model to develop a predictive tool contributing to downstream process optimization

- Consider local resources as alternatives to more distant ones

A good illustration of how georesources could contribute to the goals of sustainable development is given by high-tech elements such as for example germanium. Germanium is an essential metal in manufacturing fiber optics for high speed data transfer. An estimated 4000 t germanium is currently "in use" (tertiary resource) which, even if entirely recycled, is by far not enough to face the expected needs for connecting the world. More germanium has to be sourced from the earth crust, but the current production in China is obtained by burning coal and leaching the residual ashes… a clearly non sustainable choice, when put in balance with alternative resources such as European zinc mineralisations.

### *2.2 Mining and Minerals Engineering*

Mining and minerals engineering have disappeared from many curricula, with the consequence that these disciplines are often considered as a combination of well-established techniques with no or very limited potential for innovation (Cilliers, 2014). In order to overturn this reality, especially in Europe, it is urgent to reinvest into this education field and to build programs inviting young engineers to tackle ambitious challenges in a creative and innovative way. Some examples are:

- The invisible mine
- Mining robots (unmanned extractive operations)
- Sensor-based automation
- Biodegradable reactives in mineral processing
- Smart sorting technologies
- Beneficiation of low grade ores

Innovation and creativity are often triggered by setting up challenges and competitions which draw the attention of the general public and make visible the contributions of engineers to a more sustainable world. The Shell Eco Marathon and the Eurobot cups are just two examples of competitions which are popular in engineering schools and have contributed their share of innovations.
Similar fascinating challenges could be set up to adress needs in mining and minerals engineering and make sure the most ingenious teams will contribute. Examples are the development of smart and miniaturized mining robots to avoid extracting waste rock or the development of fast dismantling technologies for recycling end-of-life products.

### *2.3 Materials and Product Design Engineers*

The evolution of materials throughout the ages illustrates how much our modern technologies rely on very elaborate composite materials, alloys, lightweight structures, etc. Product design engineers work today with very extensive databases of materials which satisfy most of their expectations in terms of functionality and allow them to bring to the market very elaborate technologies. As illustrated by fig. 2, functionality has been the main driver of technological evolution in the last decades. It is only recently that the idea of sustainability has made its way into material selection and product design, being mostly taken into account through lifecycle analysis (LCA) principles. Despite the progress made in this field it appears that much work still needs to be done to properly account for (abiotic) resource depletion and to include some indication of product recyclability. If we want materials engineers and product designers to contribute to sustainable development and to a more circular economy we need to confront them with the challenge of recycling. Within the RM Academy, several initiatives are taken to organize Circular Economy Design courses or Innovative Recycling modules to be offered to material scientists and product designers. It is expected that through team work and problem solving projects, they will gain awareness of the innovation paths to be followed.

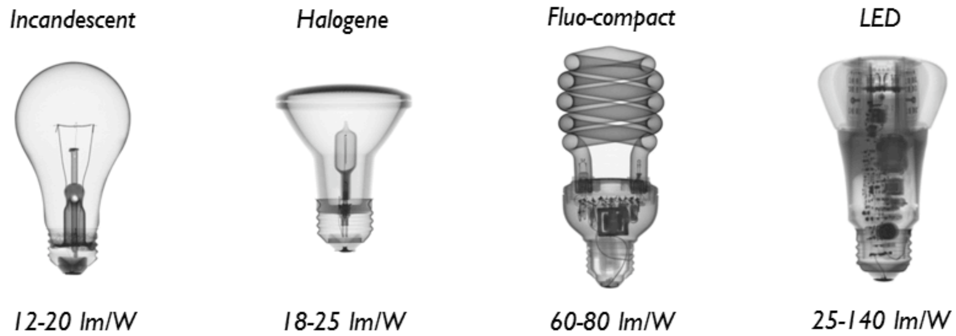


Figure 2. Evolution of light bulb technology showing increased performance (lm/W) but inducing a pressure on critical raw materials and threatening recyclability.

### *2.4 Doctoral School in Circular Economy*

Because innovation requires entrepreneurial skills, the RM Academy is developing a whole range of Summer Schools offering a blend of circular economy challenges and entrepreneurship courses. A very recent example is the first edition of the PhD Summer School in Circular Economy jointly set up by U Gent, KU Leuven, U Liege and RWTH Aachen (DocSumSco, 2016). PhD students from different horizons (business schools; engineering; environmental sciences;…) participated to a one week immersive summer school and were confronted with the need for innovation to limit e-waste and enhance their recycling. After a series of courses and testimonials, students were invited to develop their own project in team work and present a possible business model.

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# Engineering Education for Sustainable Cities in Africa

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**Abstract**

Rapid and large-scale urbanization, together with a drive towards environmental and financial sustainability, creates considerable challenges and opportunities for engineers and engineering education in Africa. The number of African cities with over 5 million in population will grow from 10 today to over 60 in 2100, when African cities will make up 5 of the top 10 worldwide. This trend will place significant demands on the continent, which must be met in light of resource constraints and environmental considerations. The central challenge is to ensure that sustainable infrastructure enables African cities to grow by multiples in population and economic strength while growing disproportionately slower in terms of costs, greenhouse gas emissions and other pertinent factors. To achieve these goals in Africa requires sustained and effective efforts to develop new approaches to building sustainable infrastructure at low costs, identify the extent and nature of engineering knowledge and talent needed to build sustainable cities, and devise new approaches to scale up engineering education and talent production efforts to meet the required cadre of engineers and fill skill-gaps without compromising on quality. Meeting these objectives will require contextualizing and re-imagining engineering education. This paper presents a review of the status of engineering education in Sub-Saharan Africa (SSA), opportunities and challenges that its academic institutions encounter, and the extent to which new training models based on information technologies are being implemented. We focus on SSA as resource constraints amplify related challenges, while simultaneously, innovation in education can have great social and environmental impacts.

## 1 Introduction

### *1.1 Urbanization, Globalization and Climate Change*

Massive urbanization is expected to be a defining characteristic of the 21$^{st}$ Century, with the most extreme growth in African cities. The number of African cities with over 5 million in population will grow from 10 in 2010 (about 10% of global share) to 67 in 2100 (representing 43% of such cities globally) (Hoornweg *et al.*, 2014). In 2010, only one African city (Lagos, Nigeria) was among the world's 25 largest cities. By the year 2050, the populations of Dar es Salaam, Khartoum, Cairo, Lagos and Kinshasa will range from 16 to 35 million. By 2100 our forecasts show African cities will make up 5 of the top 10 cities in the world by population, and 16 of the top 25, with the largest having 80 to 90 million residents (Hoornweg & Pope, 2014). Infrastructure expansion in areas as diverse as energy, transportation, buildings, water and wastewater will be necessary to accommodate the tremendous growth in cities. In light of resource constraints and environmental considerations, we must ensure that the new infrastructure is built with sustainability as a core principle. The key question is how does Africa prepare for this looming transition? Here we take a broad look at the state of higher education in Africa, with emphasis on engineering, which will arguably be the most critical element in ensuring that future megacities are built in an affordable, sustainable and environmentally conscious manner.

### *1.2 Engineering Education in Africa*

Domestic development of science, technology and engineering capacity in sub-Saharan Africa (SSA) is a critical prerequisite to realizing development objectives. The discourse on development is "shifting from emergency and relief operations to long-term endogenous solutions based on building endogenous technical competence and stimulating local entrepreneurship" (Juma, 2006). In line with this thinking, greater focus is being placed on the higher education sector in Africa overall with an emphasis on technical training. A significant cohort of new higher education institutions, including some private universities, are emerging in what would previously be considered unusual places.

Historically, many African universities were focused on the social sciences, in part due to a lack of adequate facilities needed for science and engineering education, which is indicative of the challenges within SSA. In East Africa, for example, engineering education was initially only offered in what is now called the University of Nairobi in Kenya, which also served students from Tanzania and Uganda, and where there was better infrastructure and industrial base to study engineering (Kumar *et al.*, 2004). In Southern Africa, South Africa is the locus of engineering education because of its relatively well-developed infrastructure and its richness in minerals, where universities such as the University of Cape Town have developed interdisciplinary and mineral–oriented engineering programs (Kumar *et al.*, 2004). In East and Central Africa, the formation of the East African Community helped unify the education system in Kenya, Tanzania and Uganda, though its subsequent dismantling resulted in other countries starting their own engineering programs. A foundation upon which the internationalization of university programs was possible was established by the West African Examination Council, which allowed countries like Liberia and Sierra Leone (that are economically and politically less stable) to benefit from expensively-run engineering programs in higher education in countries like Ghana and Nigeria (Kumar *et al.*, 2004). There are signs of progress in higher education capacity-building (including private sector institutions). For instance, in terms of overall publication rates, most areas in SSA witnessed substantial growth between 2003 and 2012 (8.5-12.7% in terms of compound annual growth rate), although health science publications hold a majority share (40-50%) (World Bank, 2014). The region as a whole relies disproportionately on foreign collaborations and transitory/visiting researchers (World Bank, 2014). The effectiveness of new higher education institutions in promoting Africa's endogenous capacity in science and technology (S&T) has yet to be demonstrated.

### *1.3 Engineering Capacity Needs and the Role of Engineers in Sustainable Development*

Many of the development goals have fallen on the limited supply of engineers to address. In SSA, this engineering capacity need has been pointed out in studies, along with its potential to hinder development. The Millennium Development Goals (MDGs) are underscored by energy, infrastructure and water, though the emphasis on health and education in the MDGs, have attracted more donors and resulted in an investment deficit in infrastructure, energy and water (RAE, 2006). The Sustainable Development Goals, replacing the MDGs, have a goal (Goal 11) dedicated to addressing cities, pledging to "make cities and human settlements inclusive, safe, resilient and sustainable". For capacity building this entails good governance, adopting appropriate standards, ensuring the integration of social, economic and environmental factors when devising engineering solutions, improving engineering education, encouraging entrepreneurship and innovation (RAE, 2006). The scalability of capacity building is paramount to economic growth and development in SSA.

While engineers have a critical role to play in sustainable development, it is recognized that the severe shortage of engineers is a threat to development, particularly as the world moves to a low-carbon economy prompted by climate change challenges. Handling climate change at the detailed microeconomic level in cities can positively change the economy by promoting green growth. One example of bridging the cities of developing and developed countries lies in energy systems. To reduce emissions, cities in developed countries need to adopt more renewable energy sources; and in developing countries, energy systems are needed more to aid development than to address climate change. The two worldviews are connected when renewable sources of energy are encouraged.

## 2 State of Engineering Practice and Engineering Education in Africa

### *2.1 Engineering Talent Production in Africa*

There is an overall lack of reliable and comprehensive data on enrolment, graduation, and employment of engineering talent in SSA, although some attempts have been made to elucidate talent demand and production in the continent. UNESCO (2010) estimated a shortfall of 2.5 million engineers and technicians required to meet water/sanitation MDGs, and highlighted a decline in enrolment and the adverse impact of brain drain. Similarly, the Royal Academy of Engineering (2012) also confirms this finding, and links the dearth of engineering talent to diminished economic growth in the region, itself mediated by persistent infrastructure gaps, reliance on costly foreign contractors, and diminished ability to use science and technology for addressing local needs and productivity improvements. The underlying causes of these factors included underinvestment in skill development, poorly-resourced training institutions, underdeveloped regulatory/standards regimes, inadequate training of engineers impacting on employability.

Perhaps the best statistical data available comes from a report entitled "An empirical overview of eight flagship universities in Africa" that gauged enrolment and graduation, student to staff ratios, and publications by resident scholars between 2001 and 2011 (Bunting *et al.*, 2014). The universities considered leading and forward-looking include: University of Botswana, University of Cape Town (South Africa), University of Dar es Salaam (Tanzania), Eduardo Mondlane University (Mozambique), University of Ghana, University of Mauritius, Makerere University (Uganda), and University of Nairobi (Kenya). Although overall enrolment grew significantly in most, enrolment in S&T areas stagnated or declined slightly. Only the University of Cape Town and Mauritius had S&T enrolment growth greater than 40% (relative to 30% average). Graduate enrolment grew (10% for masters level and 8% for doctoral degrees, annually on average), where some institutions stand out in particular, e.g., University of Ghana witnessed a 3- and 5-fold increase in masters and doctoral students, respectively. Only the University of Dar es Salaam witnessed a decline (masters students diminished from 2165 in 2007 to 522 in 2011). These trends are both a reflection of the state and challenges associated with science, technology and engineering training as well as employment prospects for graduates.

### *2.2 Efforts to Improve Science, Technology, Engineering and Math (STEM) in Africa*

A variety of local and foreign organizations are involved in the development of higher education in Africa including foundations, non-governmental organizations (NGOs), regional coordinators, and local governments; which share objectives towards making higher quality education more accessible and promoting enrollment in STEM programs. Many initiatives span across borders and provide support to large networks of universities (Mohamedbhai, 2014). Examples include: Regional Initiative in Science and Engineering (RISE), which supports graduate scientists and engineers; African Network for Scientific and Technological Institutions (ANSTI), an NGO that facilitates collaboration among African scientific institutions; and Partnership for Applied Science, Engineering and Technology (PASET), a scholarship and innovations fund for African students in Applied Science and Engineering. Initiatives like the MasterCard Foundation Scholars Program provide opportunities for African students to pursue education in STEM locally and abroad. The US-based Partnership for Higher Education in Africa (PHEA) offered academic support and institutional development for ICT access, libraries, facilities and infrastructure benefiting 4.1 million African students at 379 colleges and universities in nine[1] countries (Grant Lewis *et al.*, 2010).

Africa has also attracted attention from foreign universities, especially those based in the United States, Australia, and Great Britain for student exchange, study-abroad programs, and student recruitment more generally (Kumar *et al.*, 2004). One of the more prominent partnerships between US and African universities is funded through the United States Agency for International Development (USAID) and Higher Education for Development, which aims to address development challenges by improving higher education. A number of Western universities have collaborative programs with counterparts in Africa for capacity building in S&T, e.g., Addis Ababa University (Ethiopia) with the University of Connecticut in water resources engineering and with the University of Toronto on strengthening medical and engineering programs, University of Nairobi and Colorado State University on sustainability of dry-land communities, and University of Malawi and Michigan State University on agro-ecosystem services. Activities/offerings by foreign universities typically include training for faculty, students, and staff (through courses, seminars and workshops), community outreach activities, joint research between partner universities, curriculum design, and internship programs.

## 3 Engineering Education, Tools of the 21st Century & Promises for Africa

Distance learning and online or e-learning approaches create potential opportunities to educate a larger number of students and expand the reach of qualified academic instructors. These approaches are highly dependent on Information & Communication Technologies (ICTs) (Ibezim, 2013), which remain underdeveloped in many parts of Africa (Kashorda, 2014). While recent studies in Eastern Africa have shown improvements within some universities, many others lack preparedness to adopt online learning into their curricula, though this lag in adoption is not unique to Africa (Kashorda, 2014). Despite considerable progress, there is active debate about the efficacy of online learning tools with respect to training scientists and engineers. We review a few technological approaches that are relevant to engineering education, with a view to exploring their use and potential in SSA.

### *3.1 Online Learning/e-Learning*

Despite infrastructure challenges and the ongoing efficacy debate, several universities have introduced distance and online learning initiatives throughout SSA. Notably, the African Virtual University was established in Kenya in 2002 as a Pan-African university that provides online degrees, certificate and diploma programs. Various universities have also collaborated in the development of online content (e.g. between University of Nairobi and Moi University in Kenya). The Open University of Tanzania was established in 1992 and provides distance learning through various media, including printed material, CD-ROM and online learning management system with the anticipation of transitioning to ICT delivery as the prominent delivery method in the future. Some universities have incorporated online content into their curricula. Examples include the Center for Open and Distance Learning at the University of Nairobi, and the Digital School of Virtual and Open Learning at Kenyatta University, which provides tablets pre-loaded with curriculum content. Distance/online learning programs utilize

[1] Egypt, Kenya, Uganda, Tanzania, Madagascar, Mozambique, South Africa, Nigeria, and Ghana.

teaching platforms, specifically designed for distance education. Below we review a few technology platforms, their relevance to engineering education and the extent of their utilization in Africa.

### *3.2 Online Education Platforms*

A cursory survey of the four largest online Massive Open Online Course (MOOC) platforms (including EdX, Coursera, Udacity and Udemy) shows that engineering courses are among the most popular offerings. EdX led the group (as of 2016) with 135 engineering MOOCs from 39 different universities around the world, Coursera offered a total of 56 courses from 18 different universities, Udacity and Udemy offered 53 and 18 courses, respectfully. An example of leveraging MOOCs in an African context includes a 2008 partnership among the World Bank, Tanzanian Government and Coursera in a program to enhance skills for the knowledge economy (Boga & McGreal, 2014). Boga & McGreal (2014) suggest that harnessing the power of adaptable online content in MOOCs with the ubiquity of mobile phones would help educate more people in the developing world. Mobile devices can provide access to high-speed internet from anywhere at any time, foster social networks and digital environments, and aide in the scalability of online learning. Associated risks can be minimized using open-source platforms (e.g. edX) and enabling locals to tailor content (Garcia-Febo, 2014).

### *3.3 Remote and Virtual Laboratories*

It is generally agreed that hands-on laboratories are an essential part of engineering education (Chen, 2010; Ma & Nickerson, 2006; Feisel & Rosa, 2005; Corter *et al.*, 2004), as they are believed to improve practical skills, and nurture design, problem solving and analytical skills (Abdulwahed & Nagy, 2009). However, such laboratories are expensive to set-up and operate (Corter *et al.*, 2011; Reid & Shah, 2007). In addition, the relatively high cost of computers and challenges associated with internet access contribute to a persistent lack of adequate laboratories in Africa (Owolabi & Rafiu, 2010; Falade, 2011). Some of the challenges associated with internet access (e.g., slow downloads) are overcome via LAN installations and computer service brokers on campuses (Harward *et al.*, 2008).

Two main strategies have been developed to leverage ICTs for laboratory training, collectively referred to as virtual and remote laboratories (VRLs). These can provide opportunities for students to perform experiments, while substantially reducing the costs associated with traditional laboratories (Harward *et al.*, 2008). Virtual labs are computer software/models, which provide simulated data (Heradio *et al.*, 2016). Remote labs provide access to real laboratory equipment via the internet irrespective of students' location relative to the lab equipment (Heradio *et al.*, 2016; Feisel & Rosa, 2005). iLabs is a system for remote labs developed by Prof. Jesis A. Del Alamo at Massachusetts Institute of Technology (MIT) in 1998 (Harward *et al.*, 2008). Most VRLs are in electrical, electronics and control engineering, as related experiments are easier to simulate in a virtual environment; and emerging in other areas such as chemical engineering/chemistry (Heradio *et al.*, 2016).

A factor that likely limits use of VRLs in engineering education is the yet unresolved question of whether learning outcomes for virtual platforms can or should match those achieved using conventional laboratories. Results are mixed. Hanson *et al.* (2008) propose that direct comparison between lab modalities is not possible since each modality offers its own advantages/disadvantages depending on the measured learning outcomes. Others suggest that lack of hands-on use of equipment could result in loss of some learning outcomes (Lindsay *et al.*, 2010), and that the resulting "isolation" of the students could disengage them from the learning process (Feisel & Rosa, 2005). Ma & Nickerson (2006) found no standard framework to evaluate the effectiveness of lab modalities. More recent empirical analysis has shown that VRLs can provide similar learning outcomes as compared to hands on labs (Brinson, 2015). VRLs also provide opportunities to observe phenomena that cannot be easily visualized or are too dangerous or expensive (Heradio *et al.*, 2016; Feisel & Rosa, 2005). Each type of lab (physical, virtual and remote) has its strengths and drawbacks; and researchers have looked into combining the modalities (Zacharia, 2007; Abdulwahed & Nagy, 2011).

Notwithstanding uncertainty around the efficacy of VRLs for learning and accessibility challenges, the potential of such strategies has stimulated new programs in Africa. The advent of technologies such as the National Instruments Educational Laboratory Virtual Instrumentation Suite (ELVIS), allows more labs to be set up. ELVIS is a small, low cost device that allows performing tests using function generators, oscilloscopes and dynamic signal analyzer, which universities in Africa could use to build VRLs more conveniently since they are hosted on campus and can be accessed by local area networks (Mwikirize *et al.*, 2011). The most prominent example of VRL use in Africa is the Carnegie-supported collaboration of MIT with three African universities: Obafemi Awolowo University (Nigeria), Makerere University and the University of Dar es Salaam (Mwikirize *et al.*, 2011). While attempts have been made in Africa to build VRLs, it is not clear why this technology has not seen greater uptake given the potential benefits in cost-savings and enhancing student access.

## 4 Reflections and Outstanding Questions

For largely historical reasons there is an institutional tendency in SSA to follow past practices and conventional educational approaches when training engineers. Analysis suggests that many African universities are still developing in terms of the quality of education and training that they confer on their graduates. Reasons are varied and undoubtedly influenced by resource constraints in many cases. However, the educational models that predominate in old institutions, and which largely shape new ones as well, may also be unduly restricting progress. The old models are now being challenged, in developed and developing worlds alike, by new demands dictated by emerging realities nationally/regionally and globally, technological advances, rising cost of education, and by the sheer numbers of students.

Rapid urbanization combined with environmental and resource considerations mean that Africa is likely to face a double burden in terms of engineering capacity in the decades ahead. On the one hand the expected rise in demand for engineering talent is met with relatively limited capacity to train engineers locally. On the other, to the extent that the continent trains world-class engineers, they may not be appropriately trained from an urban sustainability perspective, and are subject to brain drain. There is a disconnect between the "engineer" that Africa needs and what it currently supplies, both quantitatively and qualitatively. If urbanization predications hold true, we can expect that these shortcomings will result in inadequate urban infrastructure, with ramifications in Africa and globally.

In this paper we presented a snapshot of some of the most salient aspects of engineering and engineering education in Africa and reviewed technological approaches that offer potential solutions. We note a need to better articulate what "sustainable engineering" or "engineering for sustainability" means, particularly in the context of resource-constrained settings of SSA, especially in light of rapid urbanization. What is also unclear is how a sufficient number of engineers can be trained to meet the projected demand in Africa. Evidence points to the need for new engineering education models that are appropriate for scale-up of talent production, with a view towards leveraging engineering for sustainable development. This exploration is part of our broader objective to examine pedagogical approaches to cities engineering and engineering education for sustainability. Questions that we grapple with in our research include: In what ways can engineering education be scaled up without compromising on quality? How best can this engineering education be delivered? How can we leverage ICTs to achieve scale and sustainability objectives? What skills are essential for building new African (mega)cities? How is sustainable engineering characterized in teaching and practice? And, what local institutional innovations are needed to usher a new era of engineering education in Africa?

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# Improving STEM and ESL Education in Nicaragua Using Modern Learning Tools and Energy Technologies

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## Abstract

This paper analyzes the education system in Waslala, Nicaragua, by focusing on STEM (Science, Technology, Engineering, Math) and ESL (English as a Second Language); two vital areas in sustainable development. A whole systems perspective with a framework on sustainability is used to investigate the factors affecting the present education system. Waslala is a remote and somewhat isolated region in the mountainous and underdeveloped region of North Central Nicaragua, and has been severely impacted by the country's civil war. The proficiencies in STEM and ESL are extremely low in Waslala when currently modern technologies in renewable energy and information and communication (ICT) technologies are rapidly developing in the region. The STEM education is not keeping up with the rapid influx of technology. A few case studies are included to portray how a lack of expertise in STEM fields can cause innovative technological systems to collapse, and as a result, cause a failure to provide needy services to the poor, such as electricity. Using the STEEP (Social, Technology, Environmental, Economic, Political) model for sustainability, this paper aims to explore innovative technologies in the areas of education and energy that could be used in order to increase the reliability of technological systems and enhance the learning environment to promote, encourage, and inspire STEM, ESL and other topics related to sustainable development. Similar initiatives in Nicaragua and the developing world will be used as a basis to construct a prototype educational model specifically designed to meet the demands of Waslala at two schools, one public and one private. Sustainable policies are built around the design to make it a long lasting force in education with the intention of strengthening the social foundation of the poor while minimizing environmental impacts.

## 1 Introduction

One of the most essential areas for sustainable development is education. With an adequate education, one can acquire new knowledge. With more skills gained, one feels empowered. The more power one has, the easier it is to implement change. Positive change is the main goal for sustainable development in poor countries. The education system in many of these countries is inadequate due to limited public services, corrupt governments and rampant poverty, among other reasons. This puts many of the young people at a disadvantage; they are not properly educated and are limited in opportunities to eventually make a living and achieve their goals and dreams.

In conducting this educational experiment in Waslala, Nicaragua, STEM and ESL are the two subject areas of focus. Both areas are essential to sustainable development and most people in Waslala of all ages typically lack sufficient proficiencies. Our approach begins with an observation of the entire infrastructure of the town of Waslala and the surrounding rural communities using a whole systems analysis based on the STEEP (Social, Technology, Environmental, Economic, Political) methodology.

Using the STEEP approach the way each of the areas vital to development are performing, such as healthcare, potable water systems, and job opportunities, becomes apparent.

We then use the whole systems frame to zoom in specifically on education as an area to improve. Finally, we can then see how all the other major areas in sustainable development are positively impacted by strengthening education, by zooming back out and looking at Waslala again from the STEEP perspective. (See Figure 1)

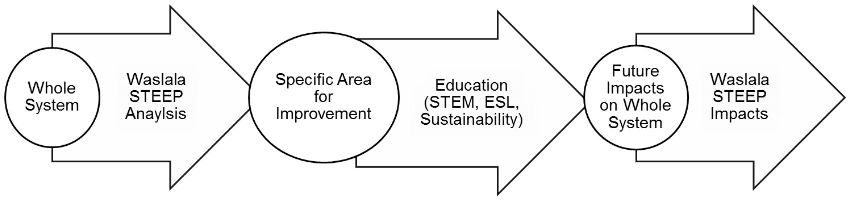


Figure 1: The 3-step approach to sustainable development used to improve education in Waslala

## 2 Background

### 2.1 Waslala

Waslala is located in the mountainous, north-central region of Nicaragua approximately 240 km from the capital, Managua. The roads in the municipality are underdeveloped and unpaved, making transportation slow and difficult. This also makes Waslala inaccessible limiting commerce and thereby growth, and development, especially during the rainy season. Less than half the region has access to electricity, which is not always reliable. The Waslala region severely suffered from the Nicaraguan civil war in the 80s. Many adults were not able to finish primary school because of the war. A major earthquake in 1978 destroyed much of Managua, which was the largest, most developed metropolitan city in all of Central America prior to the earthquake. Both the war and the earthquake, combined with the extensive corruption in the government at all levels, have caused Nicaragua to fall behind in development. As a result, the public services Nicaragua offers to rural populations is very limited.

### 2.2 Growth and Development

Although the rural regions surrounding the town of Waslala face many challenges, there are plenty of opportunities for improvement. On the bright side, over the past 10 years the Waslala region has seen an influx of technologies, such as the installation of micro-hydroelectric systems to power rural communities, rooftop PV systems for personal home use, and cellular network coverage at 2G/3G speeds. Unfortunately, it takes quite some time for the citizens of Waslala to adapt to these technologies and learn how to incorporate them into their lifestyles. Many of them misuse appliances and fail to properly maintain these vital systems. For example, micro-hydroelectric systems are purchased and installed primarily by foreign companies from Asia or Europe, which are then managed locally by technicians with minimal expertise. A damaged component due to improper O&M may mean no electricity for the community for months since there are no parts available locally or even in the country.

The absence of expertise in other technology-specific endeavors such as rooftop PV systems and cell phones have also caused problems. For example, PV systems can be purchased and installed locally, but it is the responsibility of the customer to maintain it since no repair services are available. As a result, many of these PV systems end up breaking down, especially in rural areas, where there is a lot of wear and tear from dirt and dust. Cell phones are used by rural community health workers to contact the hospital in Waslala in the case of an emergency. If the cell phone stops working due to improper care, then they lose the ability to provide health care services such as emergency calls to the hospital for pregnant women in labor. Thus, if one doesn't understand a piece of technology, one can't maintain it.

### *2.3 Present Education System*

The Nicaraguan government today is primarily interested in establishing itself in the global marketplace through trade and tourism, and creating business opportunities in energy infrastructure and a grand canal. Investment in healthcare and education remains limited. The Ministry of Education prioritizes access to education, over quality of instruction. Today, many children are learning in a weak educational system. with especially limited instruction in STEM and ESL. Rural areas like the Waslala region, have many schools that are short on staff and resources such as lab materials, to be able to sufficiently teach these subjects. Only some schools have access to the unreliable, power grid, while no schools have Internet access. The electrical infrastructure at the main public school in the town of Waslala, Escueala Publica de Ruben Dario, is in poor condition. Many of the overhead lights are not working and the electrical components such as wiring and fuses are all falling apart. The classrooms are also in terrible condition, as there are shattered windows, broken desks, and damaged white boards.

The Ruben Dario Public School is one of the two schools to be studied in this project. It contains both the central primary and secondary schools, with grades ranging from 1$^{st}$ to 11$^{th}$. They follow a curriculum created by the Ministry of Education that includes most mathematics and science topics, with almost no lab work. The other school used in this study is the private school, The FUMAT (Fundación Madre Tierra) Institute. It is a supplementary educational program that follows the national curriculum. It is primarily focused on providing 3 year agricultural programs for students from rural communities in the Waslala region.

As a result of the limited staff and resources, the achievements made by students in the STEM and ESL fields are poor. Last year at the major public school in Waslala, 55 out of 65 students in 10$^{th}$ grade failed chemistry and physics. That same year, only 4 out of 47 students in 11$^{th}$ grade (final year) applied to take the admission math exam at UNI (Nicaragua National Engineering University). On average, only 10% of students pass basic math requirements for university entrance exams in Nicaragua. In 2015, only 5% of students passed the UNI admission exam. This year, none of the 4 students in Waslala who took the exam passed it.

The people of Waslala encounter many challenges in dealing with technical ventures while the students in schools are performing poorly in the subjects necessary for the design and maintenance of these technologies. They also perform poorly in English as a second language, a subject that is vital for sustainable development. English is the most common spoken language in the world. It is spoken by 1.5 billion people and is the universal language for global communication and science. As an isolated region, having more people in Waslala speak English would benefit them to become successful in higher education, obtain a respectable career, and create new jobs since they would have more foreign interaction.

## 3 Methodology

The goal of the project is to transform the education system into an innovative model that uses technology like renewable electricity as both an energy source and learning resource, in addition to modern tools such as the Internet and laptops. The pilot to be conducted at the two schools, also needs to take into account the factors that are vital to sustainability, such as the social and political structure like framework, policies, and stakeholders, and the economic model in order for the project to be financially sustainable.

### *3.1 Technical Design with Minimal Environmental Impact*

The technical design of the project is composed of educational tools that are used with a renewable energy powered nanogrid A nanogrid typically powers a few buildings, such as a school and has a power rating less than 20kW. The nanogrid will be a single phase, DC, off-grid photovoltaic system in order to maximize energy efficiency (Figure 3). The system parts are available locally at Tecnosol, a Nicaraguan renewable energy business. The design is relatively simple and avoids the need for expensive, equipment that requires maintenance such as turbines used in microhydroelectric systems. Using this system, the students can also learn firsthand how solar power works.

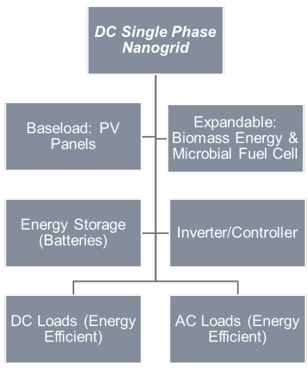


Figure 3: Basic layout of nanogrid to power school

With the addition of stable electricity, the students can enjoy a better learning environment and utilize tools that may be unfamiliar to them. Some useful appliances like LED lights and projectors can give teachers and students more and better opportunities to teach and learn. As Table 2 shows, all of the appliances listed can be powered by DC instead of AC, in order to minimize losses. All can be purchased at the local Tecnosol store or at an electronics shop in Waslala.

Table 2: List of classroom electrical appliances

| |
|---|
| LED Light |
| Ceiling Fan |
| Projector |
| LCD Display |
| Internet Modem & Wi-fi Router |
| Laptop or Tablet |

The most important tools listed are the laptop and tablet. These appliances can serve as education tools to have access to open source online content as well as educational apps and games. One recent technological innovation on the market to improve education in developing countries is the One Laptop per Child. This small laptop is durable, energy efficient, and nifty as it can transform into a tablet and drawing tool. It also can access the Internet via a wireless mesh network. Virtual learning platforms for teachers and students can be used with a stable internet connection to provide teachers with additional resources to present the subjects and students with more opportunities to better grasp the material. There are thousands of educational resources available for free online, as well as distance learning programs such as MOOCs and Khan Academy.

With these additions, the typical classroom can become a virtual classroom where students can practice and study material on their own, or watch video lectures live or recorded via the projector without the need of a teacher being present at the moment. Figure 4 below shows how this innovative design would look. Besides the upgraded classrooms, there would also be a computer lab, where students could learn computer skills, play educational math and science games, and use language-learning software such as Rosetta Stone.

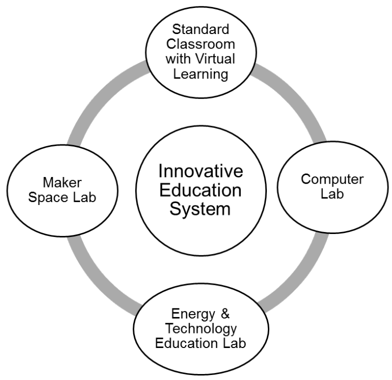


Figure 4: Architecture of innovative education model

For the lack of hands-on learning in STEM, there would be two lab spaces: An Energy and Technology Education (ETE) Lab, and a Maker Space (MS) Lab. In the ETE Lab, the students can learn how the school gets it electricity and monitor a real time display for the PV system. They can also tinker with various technologies such as computers and cell phones to get a better grasp on how these devices work. In the MS Lab, they can experiment and create various types of projects related to physics, chemistry, and engineering, and learn key concepts in design and fabrication. They can also play with STEM toys, such as LEGO education and Roominate. Both labs can provide a space for guest speakers from industry or academia to give workshops or special classes.

### *3.2 Social and Political Structure*

The social and political structure of the pilot project describes the framework, policies, and stakeholders vital to the sustainability of the innovative education system. In collaboration with Nicaraguan teachers, students, school staff, administrators, and employees of the Ministry of Education, the curriculum should be focused on strengthening STEM, ESL, and sustainability, or as a single acronym, STEEMS (Science, Technology, Engineering, English, Math, and Sustainability). They should also incorporate topics and skills important for sustainability, including: Analysis, climate change, problem solving, global awareness, whole systems thinking, human values, rights and responsibilities, critical thinking, personal development, creativity, innovation, empowerment, skills and career guidance.

Best practices and methods for teaching should be incorporated into STEM and ESL classes, given that many students in Waslala have difficulties with those subjects. For example, the innovative education model can benefit from the 3 learning types: Visual, auditory, and kinesthetic. Visual learners can take advantage of online educational videos while auditory learners can take advantage of audio recordings. Kinesthetic learners can put their hands-on skills to use in the ETE and MS labs.

For a broader learning experience, there are opportunities for international exchange and collaboration. The students in Waslala can learn from college students in Nicaragua and foreign countries.

Undergraduate and graduate engineering students can do research and projects on various topics, ranging from software development of educational apps to biomass energy, and they can teach the students in Waslala. Online collaboration is definitely feasible with an Internet connection. They could watch videos or live feeds of students from the Google Science Fair, for example, explaining about water filters made from corn or bioplastics made from banana peels. Students can also take advantage of the Internet for tutoring. They could use the computer lab to interact with foreign students to get help on difficult math problems or to learn English. In return, the Waslala students could tutor Spanish and talk about the Nicaraguan culture to any interested parties.

Regulations for maintaining the equipment would be established mainly by the school administration. Rules need to be established to ensure proper care and safety of equipment, and where and when to use the tools such as laptops in order to minimize theft and damages. Teaching the local staff how to use and maintain the equipment is of upmost importance, in addition to engaging with many local partners in Nicaragua and abroad for project implementation. Figure 5 shows all the potential stakeholders that could be involved in collaboration, including major players from academia, government, and the public and private sectors. All will work together to ensure complete sustainability.

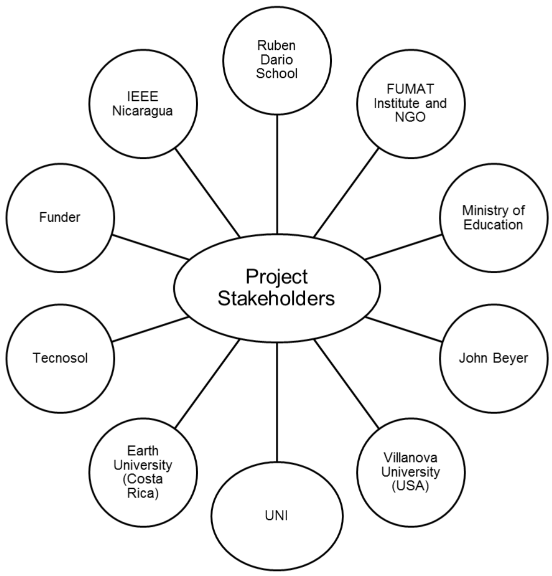


Figure 5: Project Stakeholders (All located in Nicaragua unless otherwise noted)

### *3.3 Economic Model*

There are several essential components to achieve economic sustainability. The total cost of the system must be affordable. Funding will be collected via philanthropic donations and grassroots fundraising. It would be the minimal amount required to purchase, install, and maintain the system through local staff. Funding from outside resources would also pay for long term support, such as salaries for the local staff who maintain the system. It will be limited to 10 years, until the local staff and stakeholders adopt a model to fully pay for it themselves. For example, on a small scale, the Institute could make a profit from students that pay for distance learning courses or that use the computer lab as a cyber café after school hours. On a larger scale, the Ministry of Education could entirely adopt the model into the Nicaraguan education system, paying for it internally, not from external sources. The goal is to achieve economic sustainability by providing external support and training until the point is reached where external funding is no longer needed, and so the entire system can be paid for in Nicaragua by Nicaraguans.

## 4 Outlook

In the years following its implementation, data from both schools would be collected on school statistics. We expect to notice higher scores in students' grades, especially in STEM and ESL, plus increases in academic enrollment, passing and retention rates, satisfaction of education, and a developed interest in learning and acquiring new knowledge. It is important to conduct surveys on the motivation and interest of students and teachers in the project to get feedback. Surveys are being developed and will be conducted in the near future. The results of the survey will be included in the final version of the paper. Furthermore, details of the STEEP analysis of the educational system will be included in the final version of the paper.

## 5 Conclusion

We have developed a conceptual approach to improving both STEM and ESL education in the Waslala region of Nicaragua. The approach involves installing a solar nanogrid in the public school and using this to power labs and Internet access to extend the capabilities of the school. Teachers will be able to supplement textbook learning with online modules as well as laboratory experiments. Furthermore, engagement with foreign students through communication tools will foster connections for the students in this isolated region of Nicaragua to expose them to the outside world.

Details of a STEEP analysis of this improved educational system will be included in the final version of the paper.

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# Engineering in Developing Communities: Curriculum Development around Graduate Certificate and Professional MS Programs

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**Abstract**

The University of Colorado Boulder, USA has an almost 10-year history supporting a graduate education program in Engineering for Developing Communities (EDC). This program interfaces a dynamic engineering graduate curriculum with classes and skills development specifically to bridge this engineering training to applications in lesser developed communities and non-western cultures. The program consists of a four course sequence that focuses on how engineers can work effectively in sustainable community development. Our approach promotes the integration of social, technical, economic, institutional, and environmental activities as the foundation for sustainable development. The classes include training in field work methods, global development theory and the development industry, community assessment methods, and includes an extensive field-based experience. Students are required to synthesize and integrate knowledge acquired in their coursework and other learning experiences, and to apply theory and principles in a situation of professional practice in engineering and international development. This presentation provides an overview of the ongoing EDC graduate certificate and new professional Masters of Science Degree programs at the University of Colorado Boulder. It also presents the results of a survey conducted on past and current students involved in different aspects of the graduate certificate program. The results of the survey were used to evaluate how the EDC educational experience has shaped their graduate experience and careers.

## 1 Introduction

The Mortenson Center in Engineering for Developing Communities (MCEDC) at the University of Colorado at Boulder (CU Boulder), USA is housed in the Department of Civil, Environmental, and Architectural Engineering in the College of Engineering and Applied Science. The mission of the MCEDC is to *promote integrated and participatory solutions to international development by educating globally responsible engineering students and professionals to address the problems faced by developing communities worldwide*. The Engineering for Developing Communities program (EDC) was founded in 2003. Thanks to a generous gift from the Mortenson Family and M. A. Mortenson Company in 2009, the program's offerings expanded significantly and EDC grew into an education, research, and outreach center called the Mortenson Center in Engineering for Developing Communities (MCEDC). An overview of the EDC program is presented in Figure 1.

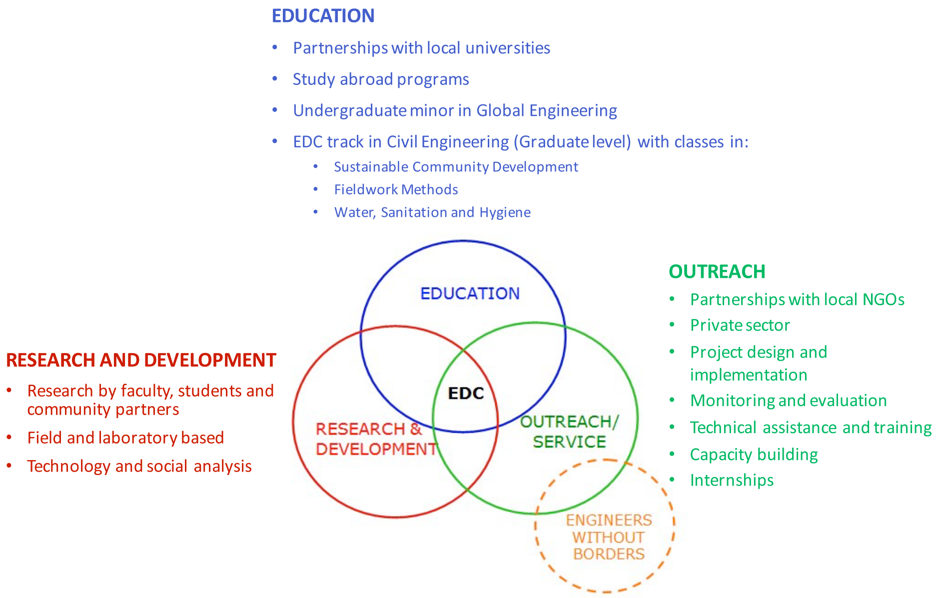


Figure 1: Overview of the Engineering in Developing Communities (EDC) program at the University of Colorado.

MCEDC offers a 4-course graduate certificate program and has recently developed curriculum for a Professional Masters of Science Degree Program (MS-PMP). A Masters of Engineering curriculum is under development. This paper presents the basic course sequence and learning objectives of the certificate program courses and the MS-PMP course structure and body of knowledge. It also presents the results of a survey conducted on past and current students involved in different aspects of the graduate certificate program. The results of the survey were used to evaluate how the EDC educational experience has shaped their graduate experience and careers.

## 2 EDC Graduate Certificate Program

The EDC Graduate Certificate consists of four classes (12 semester credits)

- Sustainable Community Development (SCD) 1 (Fall)
- Sustainable Community Development (SCD) 2 (Spring)
- Field Methods for Practitioners (Spring)
- Sustainable Community Development Field Practicum (Summer)

This course sequence is designed for graduate engineering students and others who plan to work on human development projects in developing communities. The MCEDC promotes integrated and participatory solutions to humanitarian development by educating globally responsible engineering students and professionals to address the problems faced by developing communities worldwide.

**Sustainable Community Development 1** is designed to introduce students to the complex and inter-related nature of the development industry, providing a survey approach to understanding the major historical outcomes, theories, institutions, policies, alternatives/critiques and themes in International/community Development. Through case studies, multilateral declarations, academic papers, news clippings, films and domain experts, students understand how their work in development affects, and is affected by, other development sectors and agendas. Different perspectives and opposing views on hot topics such as aid effectiveness, business at the bottom of the pyramid, subsidies, feeding the 9 billion, and microfinance are examined. As a survey class, this is an introduction intended to create comfort talking across development discourses and sectors, and to create familiarity with the thought leaders in the field(s) so that students can create more appropriate, comprehensive, and innovative development practices and research programs.

**Sustainable Community Development 2** covers the principles, practices and strategies of appropriate technology as part of an integrated and systems approach to community-based development. The goal of this course is to examine the role of engineering in achieving transformative and sustainable development. Fundamental, cross-cutting issues facing the engineer/development practitioner are explored including: migration and displacement, gender, religion, climate change, conflict, food security, innovation, and urban resilience. These issues are introduced within the context of multidimensional strategies and solutions within selected engineering-related sectors, e.g. post-disaster reconstruction, energy, transport, housing, agriculture, environment, global health, drinking water supply, sanitation, and water resource management. Multi-sectoral solutions that successfully deliver development results are explored.

**Sustainable Community Development Field Practicum** is a learning experience carried out in partnership with various international development-oriented organizations that serve as host to the students. The practicum helps provide a true understanding of sustainable development engineering by engaging students in a significant field-based experience. The practicum requires students to synthesize and integrate knowledge acquired in EDC coursework and other learning experiences, and to apply theory and principles in a situation that approximates some aspect of professional practice in engineering and international development. The practicum is designed to help students:

- Explore the meaning and importance of global engineering practice
- Use field methods including community-based needs assessment, monitoring and evaluation, and household surveys
- Assist in the design of an engineering intervention addressing some aspect of development, e.g., water supply, housing, energy, etc.
- Experience major implementation issues, common barriers to implementation, and strategies for minimizing barriers to implementation
- Identify and observe strategies for scaling up and sustaining engineering solutions at the community level
- Apply planning, monitoring and evaluation skills to real-world problem solving; and
- Enhance practice skills of leadership, effective teamwork, and the mastery of competencies in global engineering

Over the past 5 years, MCEDC has placed almost 80 students in 60 organizations, including the ones highlighted in Figure 2 below.


Figure 2: Some of the organizations that have supported the SCD Field Practicum program.

**Fieldwork Methods** introduces methods and models that can be employed in program development and deployment. Examines the applications of participatory research, value-centric design, program scale, cross-disciplinary work, and appropriate monitoring and evaluation. The goal of this course is to build student confidence around existing evaluation toolkits and methods, while advancing multi-method approaches to designing and analyzing engineering initiatives.

## 3 Professional Masters of Science Degree Program (MS-PMP)

The MS-PMP is a new professional degree recently developed to provide a curriculum to emphasize the practical aspects of engineering for developing communities.

The course sequence is focused in the areas of:

1) Core Courses in Sustainable Community Development Theory & Practice (9 credits)
2) Competencies in Data Analysis, Systems Thinking, and Project Management (9 credits)
3) Focus Area Options (9 credits) in
   - Environmental Health
   - Construction
   - Energy
   - Engineering Management
   - Policy
4) Field Practicum (3 credits)


Details of the program are provided here:

[http://www.colorado.edu/mcedc/node/312/attachment]

At the end of the MS-PMP program, graduating students will have acquired:

- The basic knowledge, attitude and skills to be able to develop integrated and participatory solutions for community development projects in different contexts and at different scales.
- The capacity to understand and operate in an international context as part of cross-disciplinary teams
- An appreciation of the technical and non-technical issues at stake in development projects.

## 4 Analysis of the EDC Program

In 2015, MCEDC decided to conduct an internal and external analysis of the EDC program to better understand strengths and areas requiring improvement within the program. A survey questionnaire was administered to past, current, and incoming students to the EDC program in the Fall of 2015. Incoming students were students beginning the EDC program in academic year 2015-16. Current students had begun the MCEDC program in earlier semesters but had not yet received their certificate. Past students had previously completed the EDC certificate. Sixty people responded to the survey, however, not all questions required forced responses, thus the sample size for questions varied. Table 1 shows the sample sizes for the different groups.

Table 1: Sample Sizes for Groups Responding

| **Group(s)** | **Sample Size** |
|---|---|
| Past | 31-32 |
| Current | 17-18 |
| Incoming | 9-10 |
| Past & Current | 48-50 |
| Incoming & Current | 26-28 |
| All | 57-60 |

The survey covered a range of topics, including how they heard about the program, other programs that they considered, why they chose to enroll in EDC and their ratings of satisfaction and importance of various elements of the program.

Students generally chose to enroll in the EDC graduate certificate program because of their interest in engineering for development and because they want careers in the development field. Most respondents had previous development experience, with the most common experience being from Engineers Without Borders-USA (EWB-USA). Of the survey respondents, Civil Engineering was the most common undergraduate major, followed by Environmental Engineering. Most students learned about MCEDC through the website and considered programs at University of California-Berkeley, Stanford University, University of Washington, and Peace Corp programs.

Past and current students were asked to "Please indicate your *level of satisfaction* with the following aspects of your graduate experience in EDC" based on a five-point scale from 1-Very Dissatisfied to 5-Very Satisfied and "Please indicate your *level of importance* with the following aspects of your graduate experience in EDC" on a four-point scale (1: Not Important; 2: Important; 3: Very Important; 4: Extremely Important). For past students, this set of questions was forced-response. However, for current students this set of questions was not forced-response, in case any of the current students had not yet experienced any aspects of the program. Funding was included on the list of aspects of the program for current, but not past, students.

Based on Likert scale responses, Faculty, SCD 1, and Practicum Experiences were the most satisfactory aspects of the MCEDC program. Based on open-ended responses, Fellow students, Faculty, and Classes were the most satisfactory, or enjoyable parts of the program. Career Guidance, Job Search Support, Research Opportunities, and Funding were least satisfactory.

Practicum Opportunities, Practicum Experiences, and Faculty were rated as the most important aspects of the program. Facilities were rated least important. Due to its high importance, the practicum was subject to both praise and constructive criticism.

Charting the results of the importance and satisfaction questions against each other can provide even more insight into the state of the program. In Figure 3, Satisfaction and Importance are the x- and y-axis, respectively. In this manner, the aspects of the program can be divided into four quadrants: High Satisfaction, High Importance; High Satisfaction, Low Importance; Low Satisfaction, Low Importance; and Low Satisfaction, High Importance.

Practicum Experiences, Faculty, the SCD 1 course, and Interpersonal Support ranked highly in both satisfaction and importance, indicating that the MCEDC was doing a good job in these critical areas and should emphasize these aspects during recruitment. On the other hand, Funding, Practicum Guidance, Career Guidance and Job Search Support ranked high for importance but low for satisfaction. As a result, the MCEDC decided to focus on improving these areas. Areas where there was low satisfaction and low importance included SCD 2, Overall Curriculum, Research Support, and Facilities.

To respond to these needs, the MCEDC is trying to identify additional sources of funding for students. In addition, the MCEDC developed sessions where students could better prepare for their practicum and receive guidance from former students, and a session for reflection by returning practicum students. For career guidance and job search support, the MCEDC subscribed to Devex, held a session featuring university alumni working in development, and invited current development workers into SCD 2 to discuss their careers and career development.

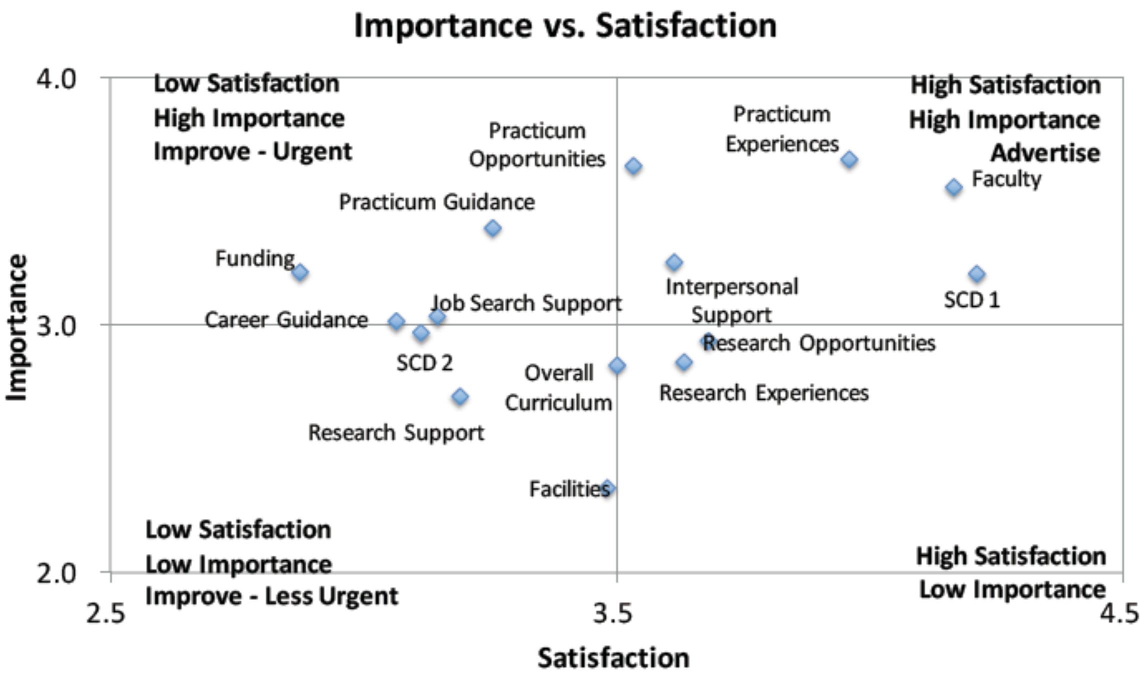


Figure 3: Competitive analysis of the EDC program indicating alumni and student satisfaction with aspects of the EDC program. SCD1, SCD2 and the Practicum are three of the core courses in the certificate program.

To analyze our coursework offerings and competitive advantage in relation to other programs, the MCEDC also undertook an external analysis of other programs in development and humanitarian engineering. That analysis, while not presented here, helped us to recognize our unique position and focus in engineering for development, allowed us to analyze our course content in comparison to other programs, and helped us focus on other areas of improvement which included identifying development-related journals, updating our website, identifying graduate fellowship opportunities for students, and identifying language learning sources.

## 5 Conclusion

The 10-year educational experience of CU Boulder's EDC program has validated both the pedagogical placement of such a program in an engineering curriculum and the strong and sustained desire of students to include this type of program in their engineering educational goals. Indeed, such a program likely draws non-traditional students into the engineering discipline. Past and current students involved in different aspects of the graduate certificate program reported that Faculty, Fellow Students, SCD 1, and Practicum Experiences were the most satisfactory aspects of the MCEDC program. Career Guidance, Job Search Support, Research Opportunities, and Funding were least satisfactory. Practicum Opportunities, Practicum Experiences, and Faculty were rated as the most important aspects of the program. Facilities were rated least important. These results were used to target areas for program investment and improvement.

# The merit of educational games in sustainability education

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## Abstract

The act of integrating sustainable development into higher education places a special set of challenges on teaching methods because of the nature of the subject. The challenge includes addressing such matters as: how to deal with complexity, how to deal with 'messy' problems, how to deal with change processes, and how to deal with stakeholder perspectives and values, to name a few. Previous studies have shown that board games and simulation games are beneficial when training students how to deal with those issues. Games offer a platform for interpersonal interaction and the possibility of experiencing simulated situations that otherwise would be too expensive or difficult to deliver in a safe training environment.

In this work, two educational games are evaluated regarding to which extent they deliver a deeper understanding of specific issues: fact-based knowledge build-up, complexity and systems thinking, and perspectives on values, from a sustainability point of view. The games used in this study are Dilemma and Fishbanks. Three undergraduate student groups at the Royal Institute of Technology in Sweden, comprising 300 students in total, are surveyed.

The study shows that games are a more effective teaching tool than traditional teaching methods. Specifically, students playing games perform better at exams than students that do not play games, and games contribute positively to students' ability to understand issues relating to systems thinking and complexity. Also, playing games increases the number of interactions between students in the classroom and lead to more discussions on the topic between students than does traditional teaching.

Keywords: educational games, board games, simulation games, innovative educational tools, innovative teaching

## 1 Introduction

Modern technology and the modern economic system is unparalleled from a historical perspective in enabling longer, healthier, richer and safer lives for a majority of the population in the world today than what most humans have experienced in history (WHO, 2015; Pinker, 2011). On the other hand, the carrying capacity of the natural systems have already been passed in many aspects and once human activities have passed certain planetary boundaries there is a risk, due to the laws of system dynamics, for irreversible and abrupt environmental change (Rockström *et al*, 2009).

There is no universally accepted definition of the term "Sustainable Development". Rather, there exists a range of definitions, with variations in details depending on ideological values (Heinberg & Lerch, 2010). Different perspectives on sustainability originate from different opinions, positions, views and stakeholder perspectives. "Sustainable Development" is indeed a subject of ***values***.

Another aspect that makes sustainability a difficult subject to learn is the fact that sustainability issues are often inherently complex. As has been shown by Meadows *et al* (1972), properties of system dynamics, such as conflicting time scales, may lead to the overexploitation of resources and eventual system collapse. Espinosa (2011) argues that this insight is reason to change the way we deal with sustainability issues today into one which takes ***complexity*** into consideration.

One professional group that is especially exposed to sustainability related challenges on a regular basis is engineers. They work in a context were values and complexity have a large impact on decision-making on all levels, with potentially large consequences (Fenner & Cruickshank 2014). Engineering is about finding solutions to technological, social, economic, environmental and other challenges by putting empirical method and science into practical implementation. Arguably, engineers have a significant role in the process of turning the direction of society onto a sustainable path.

The act of integrating sustainable development into higher education places a special set of challenges on teaching methods because of the nature of the subject. Those include addressing such matters as: how to deal with complexity, how to deal with 'messy' problems, how to deal with change processes, and how to deal with stakeholder perspectives and values, to name a few. Many of those challenges can be summarised in two overarching (non-mutually exclusive) categories: issues that has to do with *values* and those that has to do with *complexity*.

Dealing with issues of values and complexity require skills that are difficult to acquire through traditional educational methods. Active learning, such as learning through simulations and games, has been strongly advocated for example by Maier & Keenan (1994) and Smith (1992). Active learning techniques require students to work together in small groups to experience, analyse, criticise and perform problem solving instead of passively listening to a lecturer. It provides practical experience and promotes education via experiential learning techniques in more complex situations.

The use of board games, simulation games and role plays have shown to be beneficial when training engineering students (Darling *et al*, 2008; Dahlin *et al* 2015), e.g. as an effective way of improving teaching efficiency, demonstrating opposing views and encouraging an element of collaboration as well as competition in a non-threatening environment. Games offer a platform for interpersonal interaction and the possibility of experiencing simulated complex situations that otherwise would be too expensive or difficult to deliver in a safe training environment.

However, merely using games per se is not sufficient to achieve any significant learning (Zapalska & Brozik, 2008). It is essential that games address explicit learning objectives and that it has been determined specifically how the games are expected to contribute in meeting those. There must also be a review where the instructor can follow up on those learning objectives, where the students' experiences are transformed into concrete learning, e.g. a debriefing seminar or an appropriate assignment task (Lederman & Fumitoshi, 1995). The format of board games is intrinsically interactive, making them appealing as platforms for interpersonal communication e.g. by demonstrating differences in values and personal position. Dahlin *et al* (2013) showed positive synergistic effects between large group lectures and playing board games, when a discussion based board game was used to stimulate conversations around sustainability issues.

In a study by Dahlin *et al* (2015), a range of seven simulation games, board games and role play games were analysed and shown to contribute positively towards meeting certain key learning objectives in the engineering education for sustainable development curriculum. With those earlier findings as a foundation, two educational games are evaluated in this paper in more depth regarding to which extent they are efficient in delivering a deeper understanding of primarily three specific issues: fact-based knowledge build-up, understanding complexity, and understanding values.

# 2 Methods

## 2.1 Teaching environment

This study was performed at the Royal Institute of Technology in Sweden (KTH), within a 1.5 ECTS course module called *Introduction to Sustainable Development for Engineers* (KTH, 2016). Games have been used within this module since the first time it was given in 2012. The module is given at several programmes and intended as a foundation for subsequent courses. The work presented in this paper is performed during delivering the introductory course module in academic year 2015-2016.

The module includes two lectures (à 3 hours), a homework assignment, self-study readings and a knowledge test. Games are used in a seminar series where the following games are played:

*Dilemma (Dahlin, 2016):* a board game where participants have to know facts about sustainability and debate various dilemmas to be successful. Skills that are developed in this game are general awareness of sustainability, and understanding different perspectives in attitudes and values.

*Fishbanks (Meadows et al, 1993):* a multiplayer computer-aided simulation game, in which participants play the role of fishing companies seeking to maximise their net worth as they have to deal with variations in fish stocks and catch. Skills that are developed in this game are systems thinking and understanding complexity.

## 2.2 Participants

Participants in this study belong to three undergraduate engineering student groups:

- ***ML1112:*** 1st year students (*n* = 102), 3 year programme, *ADS* = 11.80
- ***MJ1103:*** 1st year students (*n* = 159), 5 year programme, *ADS* = 19.50
- ***MH1025:*** 2nd year students (*n* = 39), 5 year programme, *ADS* = 18.79

where *n* designates the number of participants in each group, and *ADS* is the admission score to enter each programme (maximum 20.00). Games were used in groups ML1112 and MJ1103. Group MH1025 was a control group without any game sessions but with a lecture (45 min) on complexity instead, and otherwise identical teaching. All groups received otherwise the same traditional teaching.

## 2.3 Measures

### 2.3.1 Survey questionnaire

A questionnaire is given to the students before and after the course module, consisting of several closed-ended and open-ended questions. The closed-ended questions, intended to measure the students' own perception of their understanding and how the topic relates to the engineering profession, are:

*Q1. "How good is your understanding of the topic of sustainable development?"*
*Q2. "How important is the topic of sustainable development for professional engineers?"*
*Q3. "How important do you think your future employer will think that it is that you have knowledge in sustainable development?"*

They are measured on a 5-point scale where 1= poor/not at all important and 5 = good/very important. The open-ended questions are included in the post-module questionnaire and intended to measure the students' opinions on how games contributed to their learning. Those are:

*Q4. "List three things that you appreciated by playing Dilemma?"*
*Q5. "List three things that you appreciated by playing Fishbanks?"*
*Q6. "What impact did board games have on your learning of sustainable development?"*

The survey questionnaire is performed digitally online. It is distributed 1-2 weeks before the course module, and opened again 1-4 weeks after the course module.

### *2.3.2 Computerised knowledge test*

The computerised knowledge test is a multiple choice test with 40 questions randomly selected from a large question bank, being two hours long and set in an exam hall with a certified exam guard present. The passing score is 30/40 in all cases. The objective of the knowledge test is to evaluate whether students had read and understood the content of the course literature.

### *2.3.3 Homework assignment*

For the homework assignment, the students are expected to find a system (natural or anthropogenic) with complexity features and competing time scales. Specifically, the system should demonstrate a tendency for system collapse. In groups ML1112 and MJ1103 this assignment is given in connection with the Fishbanks seminar. In group MH1025 the assignment is given in connection with a traditional lecture providing a theoretical discussion of such a system.

The assignment (maximum 2000 words, one week duration) is performed individually and rated pass/fail. There is also a meta-assessment, performed exclusively for acquiring data for this study, on a 3-point scale where 1 = fair, 2 = good, 3 = excellent.

### *2.4 Hypothesis*

The hypothesis of this paper is that games are a more effective teaching tool for education in sustainable development than traditional teaching. In particular, games are well suited for learning towards the following learning objectives: (i) learning to comprehend different perspectives in attitudes and values concerning sustainability issues; (ii) learning to understand complexity and systems thinking; and (iii) general awareness of sustainability and learning basic facts.

## 3 Results

### *3.1 Result of the survey questionnaire*

The response frequencies of the pre- and post-module survey questionnaire, for all student groups, are shown in Table 1.Response frequencies are considered fairly high and consistent over all groups.

**Table 1: Response frequencies of the pre- and post-module survey questionnaire, in all student groups.**

| *Response frequency, before or after course module* | | |
|---|---|---|
| Student group | Before | After |
| ML1112 | 62% | 23% |
| MJ1103 | 48% | 25% |
| MH1025 | 87% | 25% |

The results from the closed-ended questions *Q1*-*Q3* are presented in Figures 1-3.

In Figure 1, the students' perception of their own understanding of the subject is presented (*Q1*, section 2.3.1). It is clear that in all three groups, the general perception of understanding sustainability increased from the pre-module to the post-module surveys. The trend is more pronounced in courses ML1112 and MJ1103 (the mean value $M$ increased from $M$ = 3.0 to $M$ = 3.9 and from $M$ = 3.0 to $M$ = 4.0 respectively), than in the control group MH1025 ($M$ increased from $M$ = 3.4 to $M$ = 3.7). This indicates that games were effective.

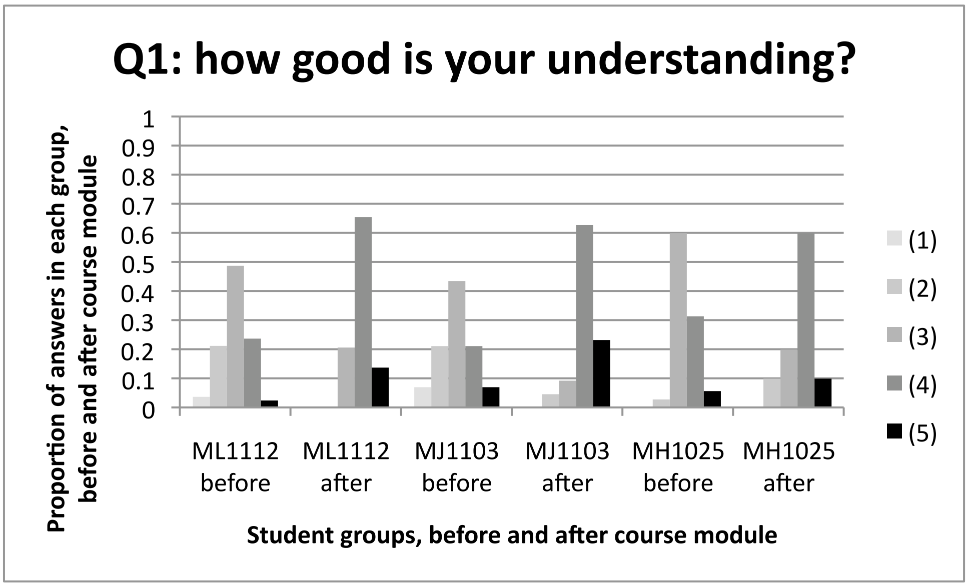


**Figure 1:** Student perception of their understanding of the topic on a 5-point scale from 1 (poor) to 5 (good).

The students' opinion on how important the topic is for their own future professional career as engineers is shown in Figure 2 (*Q2*, section 2.3.1). Unlike for *Q1*, no clear difference is seen between pre- and post-module in this case, or between courses. Interestingly though, Figure 2 indicates that students believe that sustainability is indeed an important subject for engineers to be knowledgeable in, all mean values being in the range $M = 4.2$ to $M = 4.7$.

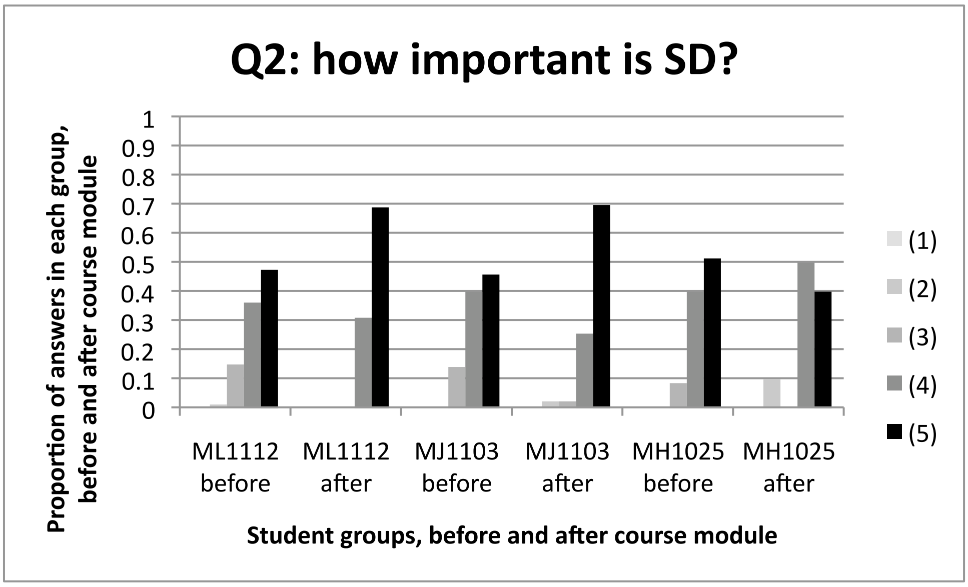


**Figure 2:** Students' opinion on how important the topic is for their own future professional career as engineers, on a 5-point scale from 1 (not at all) to 5 (very important).

In Figure 3, it is shown how important the students believe their future employer will think that it is that they have knowledge in sustainable development. Mean values range from $M = 3.8$ to $M = 4.2$ with relatively small changes between pre- and post-module answers.

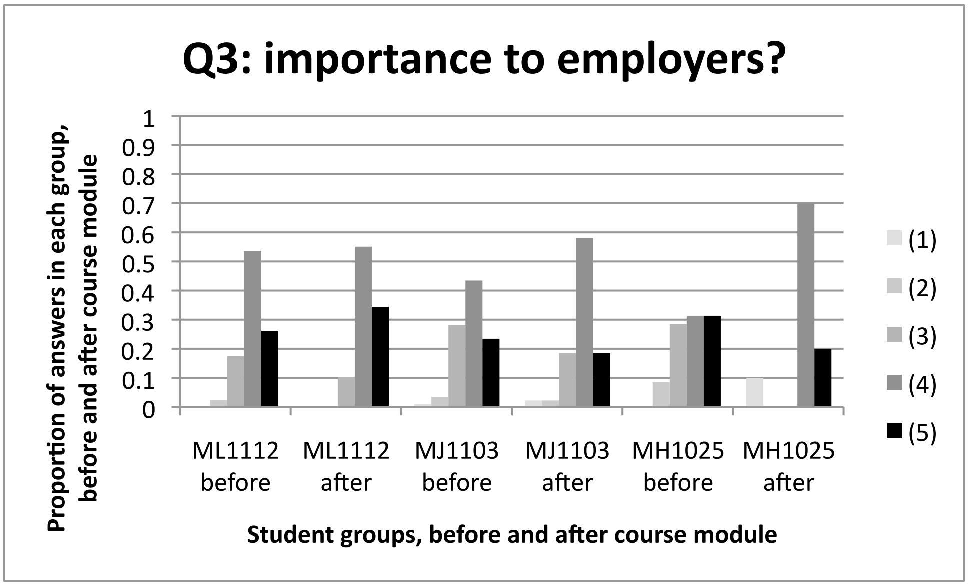


**Figure 3:** Students' view on how important they believe their future employer will think it is that they are knowledgeable in sustainable development, on a 5-point scale from 1 (not at all) to 5 (very important).

The results from the open-ended questions *Q4-Q6* are not presented in detail here since they consist of circa 200 text strings. A more thorough review of this material will be presented elsewhere, but it is interesting to point out briefly a few results:

*Games lead to an increased number of interactions between students in the classroom.* Almost all students respond positively regarding the use of games and many of them mention specifically how the games gave them the opportunity to interact with others. Quotes like this are common: "Your ability to debate and having an opinion increases thanks to the many interactions with other students".

*Playing games lead to more discussions on the topic between students than traditional teaching.* Many of the students explicitly mention the value they got from debating.

## *3.2 Result of the computerised knowledge test*

The result of the computerised knowledge test indicate that the use of games improve the students' knowledge build-up. In Table 2 the test results are presented for all three student groups, as the mean result (on a scale from 0-40) and the fraction of students with a pass score (at least 30 points).

**Table 2: Test result (mean value) and fraction of students with a pass score.**

| Student group | Mean result | Fraction of students with a pass score (at least 30/40) |
|---|---|---|
| ML1112 | 30.7 | 70.6 % |
| MJ1103 | 34.3 | 92.5 % |
| MH1025 | 28.4 | 33.3 % |

The most likely explanation for the difference between the groups ML1112 and MJ1103 (Table 2) is the difference in student composition, seen in the admission score (*ADS*) to enter each programme. As seen in section 2.2, the *ADS* is considerably lower for group ML1112 than for group MJ1103.

The *ADS* for the control group MH1025 is almost as high as for group MJ1103, and considerably higher than for group ML1112. The difference in test result indicates that the use of games in groups ML1112 and MJ1103 enhanced their performance compared to the control group MH1025.

### *3.3 Result of the homework assignment*

The analysis on homework assignment performance indicates only minor differences between the student groups. The result of the meta-assessment (section 2.3.3) in each group is presented in Table 3.

**Table 3: Performance at the homework assignment on complexity (on a 3-point scale).**

| Student group | Mean result |
|---|---|
| ML1112 | 1.72 |
| MJ1103 | 2.05 |
| MH1025 | 2.03 |

The group ML1112 shows the lowest result. This can likely be explained by the difference in *ADS*.

## 4 Discussion

The results from the survey (3.1) and the knowledge test (3.2) indicate that the control group MH1025 acquired less learning from the module than the other groups in spite of them being a more mature group. This is a result in support of using games for knowledge build-up.

The results from the homework assignment on complexity indicate that games positively influence the students understanding of complexity. The control group performed at almost the same level as group MJ1103 (Table 3). It had been expected that the control group MH1025, being a more mature group, would perform better. This result supports using games for understanding complexity and systems thinking. However, this result is arguably not quite as strong as the previous one as there has been no attempt to normalise the results in Table 3 based on the difference in maturity. An equal score may not be regarded enough for a conclusive statement on this matter and more research would be needed.

## 5 Conclusions

This study shows that games are a more effective teaching tools than traditional teaching methods, especially in education for sustainable development. Students playing games perform better at the knowledge test than students that do not play games. Playing games also increases the number of interactions between students in the classroom and lead to more discussions on the topic between students than traditional teaching.

In particular, games contribute strongly to students' knowledge build-up as well as to their own perception of understanding the topic. It also seems that games contribute to the students' ability to understand issues relating to systems thinking and complexity, even if this trend needs more research to be confirmed.

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# Barriers towards Sustainability Integration in Engineering Education

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## Abstract

In the last decade several initiatives have been taken to integrate sustainable development in engineering education, but still the process is slow compared to the needs. In many occasions integration of education for sustainable development (ESD) is still characterised by add-on strategies through stand-alone courses, or ad-hoc green campus operations. Several studies have outlined barriers for ESD in Higher Education Institutions as well as concrete suggestions for actions to be taken. In this paper we will add to this body of literature by focusing specifically on how the understanding of sustainability can create socio-cultural barriers from a staff and students perspective. The study is conducted at the Faculty of Engineering and Science, Aalborg University (Denmark) and takes a qualitative approach, whereas 14 academic staff and 6 students from two different master programmes have been interviewed. The findings point to three types of socio-cultural barriers: 1) Challenges related to the relativism of sustainability – struggling to define or not to define sustainability 2) Decoupled discourses – avoiding talking about sustainability as a part of the discipline 3) Tunnel vision – a tendency to extend and not to expand what we know. As a perspective, the potentials embedded in exemplary interdisciplinary problem based projects designed for ESD are highlighted.

## 1 Introduction

Engineering education providers, like other professional higher education areas, have the responsibility to educate engineers capable of contributing to a sustainable society. Education for sustainable development (ESD) advocates for a whole system change where sustainability principles are integrated in the institutional paradigm, management and research, as well as teaching and learning practices. Literature provides examples of integration of Sustainable Development (SD) through mission statements, institutional commitment and strategic plans as well as barriers, which go along with the change processes (Ferrer-Balas et al., 2006; Horhota et al., 2014; Lozano et al., 2006; Lozano, 2006; Martin et al., 2006; Mulder and Jansen, 2006).

Lozano (Lozano, 2006) points to three main barriers associated to higher education: i) conservationism and maintenance of status quo; ii) extra work added to "day to day" activities; iii) lack of information regarding sustainability and its integration in professional activities (e.g. teaching and researching). Moore (2005) highlights four main barriers observed at the University of British Columbia (UBC) (Canada) when integrating ESD in existing engineering education, mainly related with i) the structure around disciplinary boundaries; ii) competitiveness within and outside the organisation; iii) evaluation criteria; iv) unclear priorities and decision-making processes. These barriers constitute an impediment of "*the implementation of sustainability*" and the fulfilment of making "*all students educated about sustainability*". Also from the Technical University of Catalonia (UPC) (Spain) different types of barriers are reported, namely i) staff skills and motivation towards SD, ii) university culture and resistance to change, iii) different levels of change (e.g. top-down and/ or bottom up), iv) lack of dissemination across the institution, v) lack of internal and external recognition (Ferrer-Balas et al., 2006).

To cope with such barriers ESD researchers call for an on-going evaluation of processes where local barriers are identified and comprehensive, multiple and tailor-made strategies are formed, including i) engaged staff already (ESD champions); ii) staff development and training on ESD; iii) knowledge banks and communication platforms for ESD within organisation; iv) a balance between compulsory and elective courses/ programmes on ESD; v) rewards and recognition systems (Ferrer-Balas et al., 2006; Lozano et al., 2006).

But besides the above-mentioned barriers, researchers have also pointed to the limitations of instructive approaches to learning in higher education (Sterling, 1991: 37):

*"It is not that instructive approaches are always inappropriate. Training in certain skills is entirely sufficient in some aspects of vocational training, for example. But even here good training becomes an applied art rather than a universal science, and will often extend into constructivist approaches. Situations that require 'higher order' or transformative learning always imply constructivist approaches and this is very largely the case with sustainability issues because of their complexity and often deeply challenging nature"*

To cope with this ESD researchers have called for active student-centred pedagogies capable to enhance student's knowledge and competencies for ESD such as: i) holistic and system thinking; ii) reflective and critical thinking; iii) interdisciplinary collaboration; iv) responsible participation and decision-making; v) problem solving (Engineering Education for Sustainable Development, 2004; Sterling, 1996; The Royal Academy of Engineering, 2005; UNESCO, 2013). One of learning methodologies used to integrate ESD in engineering curriculum is problem based, project organised learning (PBL) (see for example Brundiers et al., 2010; Dobson and Tomkinson, 2012; Sipos et al., 2008; Mulder et al., 2012; Guerra, 2014).

But even proactive institutions in terms ESD strategies and pedagogical models can struggle with the integration of ESD. In this paper we add to the literature of barriers to integrate ESD aiming specifically on getting a closer understanding of how the understanding of sustainability can create socio-cultural barriers for the integration of ESD. Thereby, more general barriers for change (such as for example conservatism and maintenance of status quo), more structural barriers (as for example an instructive learning curriculum) as well as lack of resources will not be addressed. Instead we will take the following research question as starting point:

*Which underlying socio-cultural barriers related to the understanding of sustainability can hinder proactive engineering education institutions to realise strategies for ESD?*

## 2 Methodology

To investigate socio-cultural barriers related to the understanding of sustainability, we have chosen a case-study approach which is exemplary in the sense that the chosen engineering education institution already has implemented a pedagogical model that is in alignment with ESD, has clearly stated ESD visions, has sustainability campus practices, but at the same time ESD is not yet fully integrated. In the following we present the case and the research methods.

### *2.1 Case-study at Aalborg University*

Education at Aalborg University (Denmark) has been problem based, project organised (PBL) since the foundation of the university in 1974. Furthermore, Aalborg University compromised in integrating ESD by endorsing Copernicus Campus Charter (1994) and by being a founding member of Copernicus Alliance (2007-2010) (Krogh Hansen et al., 2014b).

The Faculty of Engineering and Science comprises more than 113 B.Sc. and M.Sc. programmes. In every programme students work on projects in which they have to deal with real-life problems. Each semester is organised in three course modules of 5 ECTS[1] each and a project module of 15 ECTS. The type of problems (e.g. more or less open) and thematic frames (e.g. more disciplinary or interdisciplinary oriented) under which students formulate and solve problems vary according to the engineering programme, however the PBL approach and curriculum organisation remain the same.

The Faculty of Engineering and Science puts strong emphasis on integration of sustainability by making it part of strategic goals as it is stated in the following:

> *"We are a progressive and internationally recognised faculty that produces knowledge and original technical solutions targeted toward* ***society's "Grand Challenges****"* […] *in close interaction with the surrounding society that sets new standards for basic research and applied* ***research in global sustainable welfare and technological development****"* (Faculty of Engineering and Science, Aalborg University, 2012, p. 5)

In 2012, the Faculty started an auditing project with the aim of mapping the presence of sustainable development in engineering curricula. The results show that the faculty offers programmes in sustainable development (e.g. Sustainable Cities; Sustainable Energy Planning and Management; Environment Management and Sustainability Sciences; Sustainable Biotechnology, etc.). However, more than half of programmes do not show any presence of sustainable development in written curricula (Krogh Hansen et al., 2014a, 2014b).

### *2.2 Research methods*

This study takes a qualitative approach. In total 20 participants have been interviewed, 6 students and 14 academic staff from two engineering master programmes, M.Sc. Urban Planning and Management (UPM) and M.Sc. Structural and Civil Engineering (SCE) (Table 1). The authors are from the case-university but have not been involved in the two investigated engineering master programmes.

Table 1 Research method used and participants of the study

| Method | Participants |
| --- | --- |

[1] ECTS stands for European Credit Transfer System. At Aalborg University, one semester comprises 30 ECTS, whereas 1 ECTS is approximately 30 hours.

| | UPM | SCE |
|---|---|---|
| Semi-structured interview | 6 academic staff | 8 academic staff |
| | 6 students | 0 students |

The method used for data collection is semi-structured interviews whereas a script is constructed beforehand. The script includes how staff and students understand sustainability as well as their experiences and perspectives with the integration of ESD. Each interview took approaximatly1h30 and was recorded with interviewee permission. All the interviews' audio files were coded and analysed using N-vivo software and summarised.

## 3 Findings

This section presents three kinds of socio-cultural barriers related to the understanding of sustainability that we found in the case study at Aalborg University investigating staff and students attitudes and experiences related to the integration of ESD.

### *3.1 The relativism of sustainability*

"*Sustainability is very flexible in its interpretation* […] *I would be able to argue that almost anything can be sustainable just by having the sustainability concept widen enough*" (Academic Staff $2_{UPM}$).

Based on this perception, this staff member, teaching at the M.Sc. UPM, argues that when integrating ESD it is important to avoid broad and wide definitions of sustainability. However, the question is whether the complex nature of the sustainability concept can be appropriated into a narrow and fixed definition of sustainability. If a multitude of definitions on the other hand are to co-exist, staff and students are faced with the challenge not only to understand different definitions of sustainability but also to adopt or even develop their own definition(s) of sustainability.

Students however recognise the relative nature of the sustainability concept. One of the students at S6 UPM stressed the importance of context in the following way:

"*I think my education makes me aware about things being sustainable but it depends on how it is defined, because sustainability differs in my opinion. What is sustainability in the 3rd word countries compared to here? I do not think it is the same.*"

Another student (S5 UPM) touches upon the matter of personal perception and value base in his reply to a question considering his explicit intention to address sustainability in their project:

"*Not sustainability. There are a few elements of it. We are not discussing sustainability, saying what it is and describing the theory behind, we are not doing that. But we have something about some climate issues, or something… We are not saying what it is because that is the point about the approach we take this semester. That people have different perceptions of things, they interpret differently, so it would not make any sense to say what is this actually.*"

This quote also shows one extreme of coping with the complex nature of sustainability, to cope with the relative nature of sustainability by avoiding a definition of the term. At the other end of the continuum, another student asks for more clear definitions of sustainability:

> "*Because what you see in general is that everything is sustainable development, every municipality suddenly is sustainable. But they don't really define what it really is; they just say*

*economics. I think it is important that we need some specific measurements for the government, for the state, even for the public to understand what is going on.*" (Student $1_{UPM}$)

Student (S5 UPM) offers a reply on that position, as he claims that even though it would be interesting for an institution to have its own official understanding of sustainability, the relative nature of sustainability provides students with a learning potential:

"*I've been working with sustainability at least two semesters, and I know I have a very clear and comprehensive understanding of what sustainability is but it would be very interesting if this institution kind of has its own official understanding of sustainability. That also would have limited us, because there was this one semester where I used a lot of time describing what sustainability could be in an urban planning context. And I would not have done that if they had an explicit explanation of what it is.*" (Student $5_{UPM}$).

Learning potential or not, the confusion about the conceptualisation of sustainability is notable for both staff and students.

## *3.2 Sustainability and engineering disciplines as decoupled discourses*

Integration of sustainability in curricula implies that sustainability is not seen as an add on, but instead an integrated part of the disciplinary discourse and thereby integrated in the way people think of, talk about and practise sustainability within the chosen discipline. Due to the relative nature of sustainability, as was addressed in the former section, the understanding of sustainability can be blurred, and that does not make it easier to integrate. But even if the conceptualisation of sustainability is clear (at least for the person itself), it does not mean that staff and students can or will link sustainability to their discipline. Academic Staff $12_{SCE}$, from M.Sc. SCE, points out that sustainability has to be formulated as something relevant, concrete and related with the profession for students, so they can use and integrate it in their projects and education.

However, the interviewees from SCE characterise engineering students as goal oriented, emphasising that students' motivation is mainly related to "doing calculation", and several times it was stressed that SCE is a technical programme. About the possibilities for ESD one of the staff members (L1SCE) explains:

" *I agree we have the basic to do this, but we are not doing as much as we could do. And it is not a priority. It is not a priority*".

At the same time this staff member recognises sustainability competences as a part the profession and real life engineering:

"*Out in practice, the way to earn money is to make these links, it is not calculating, because everyone can calculate. There are a lot of pressures, a lot of programmes, and whatever, so it is where the money is, to connect the technical, the environmental and economic aspect. Everyone can calculate but not everyone can make these connections. For now at the university, we are not very good at making these connections*".

One of the reasons for these missing links at the university is grounded in the "silo" phenomenon, whereas departments and educational programmes remain within their boundaries. ESD claims for interdisciplinary knowledge and collaboration, and even though PBL is interdisciplinary and team-based in this case, there are some limitations regarding interdisciplinary practice.

Academic Staff $1_{UPM}$ points out that engineering and technical fields are very restricting, enclosing specific guidelines from the government. In this sense, it seems that interdisciplinary knowledge is more likely to be accepted in social sciences rather as part of engineering education, as it is explained in the following quote:

"*In the Danish context one of the problems is to work across things, interdisciplinary. That is because you have some strict regulations, guidelines from the government … If you are working in a technical field then it is difficult. They will say this is interdisciplinary that's fine but then you can place it in social sciences*."

Academic Staff $8_{SCE}$ adds to this by bringing attention to the lack of collaboration across different departments and programmes as stated: "*I would like to do some more cross disciplinary work, where students use their own skills together with others to do a project*". […] "*I can see it is possible because other departments are doing it. But we just haven't figured out exactly how to do it*". Academic Staff $6_{UPM}$ furthermore argues that this kind of silo phenomenon extends also to students, due to a lack of possibilities to form groups outside their own programme.

## *3.3 Tunnel vision*

The two programmes investigated are very different in nature. Whereas SCE have a stated technical focus, urban planning and management is characterised by a strong generalist focus being a more hybrid education in nature. As can be seen from the above, staff and students from the generalist education are the main voices behind barriers related to the relativism of sustainability, whereas staff in the more technical programme have a tendency to decouple the discipline from the sustainability discourse – making the need for definitions less important. However, both educations in different ways can be characterised by what Næss (2010) has termed tunnel vision.

Keeping the image of a tunnel in mind, the overall approach for SCE sometimes seems more convergent than divergent. Interviewee Academic Staff $1_{UPM}$ points out that the "*technical fields are very detailed, and if you are working in a laboratory, then you just start out with something detailed and get more and more detailed throughout the education*". Interviewee Academic Staff $8_{SCE}$ supports the above by stating that "*a big part of being an engineer is to take a complex problem and then simplifying it down to something you can actually calculate*". Academic Staff $11_{SCE}$, claims that it is difficult to bring students out of their comfort zone, moving towards the technical stuff is what makes students comfortable.

For UPM the tunnel vision is focused on contextual knowledge. One of the representatives in the study board address this in the following way (SB1 UPM):

"*UPM is too contextual and there is, if I can be very rude, there is not a core of the profession. It started out as what you can call a professional education. You say you have some planners out in the real world that should plan something – energy systems, road systems, good urban areas to live in and so on. And then you have more and more people analysing the process around the city as power relations. But what has happened with UPM, as I can see it, is that you totally lost the object – what is the object…*"

So as SCE programme brings a reductionist and technocrat approach into the tunnel leaving little room to think outside the box, the other takes a constructivist and contextual approach leaving less focus on technical details, definitions and calculations. One possibility to bring these two clearly complementary streams together could be to get the students from different programmes to work together. In this case, some incentives have been taken to make this happen. Academic Staff $2_{UPM}$ explains that "*the board of rectors have the idea that will be suitable to create cross university courses,* *kind of middle level that should be extracurricular, meaning that should not compete with specific education*".

Without the presence of a strong student movement for sustainability, this quote indicates the need for more formal integration of sustainability and inter-disciplinary project work into the curriculum. If sustainability gets inside both tunnels, in two different disciplinary curricula – sustainability might provide what Wenger (1998) would call a boundary object for inter-disciplinary learning.

## 4 Final remarks and perspectives

In this study it has been investigated how underlying socio-cultural barriers related to the understanding of sustainability can hinder proactive engineering education institutions realising strategies for ESD. The study took a qualitative approach in which 14 academic staff and 6 students were interviewed. Based on this study three types of barriers were identified:

1. Challenges to cope with the relativism of sustainability – having a hard time defining sustainability due to the complexity and context dependency embedded in the term.
2. Decoupled discourses – avoiding seeing and talking about sustainability as a part of the discipline
3. Tunnel vision – a tendency to extend and not expand what we know.

The three barriers are closely interrelated, they might co-exist and they might exist independently of the others – the most important thing is that educational designers reflect on how they can cope with the relativism of sustainability, the distinction between sustainability as a discipline and sustainability integrated in a discipline and a tunnel vision that will serve its purpose of creating a professional identity and focus without neglecting the opportunity to work interdisciplinary. Exemplary problem based projects under a sustainability theme carried out within disciplinary boarders at first and then later on in interdisciplinary teams increasing the complexity of the sustainability challenge is a possibility. In this way sustainability would not only be integrated into the discipline, it will also be linked to the inter-disciplinarily nature of engineering practise – as a two-step process.

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# The role of higher education in shaping the future economy

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**Abstract**

The biggest waste within our current economy must be human potential. Our education system is inherently wasteful and a very linear system in terms of delivery, "transmission", of knowledge and skills. There is a growing oversupply of graduates at the top. Many graduates do work which does not require what they have learnt. People are learning things that are going to be useless to hem because the world is changing so quickly. In this new world, we need a feedback-rich teaching and learning system that enables people to learn the skills that they feel are needed in a highly volatile and fast-changing economy. This system is not pointing towards a particular set of knowledge. It is preparing people to be flexible, adaptable and creative.

Options for informal ways of education and personal development are growing. Learners often go through informal education while working in the meantime. It is responsive to the current needs of the learner and is often provided by varied resources: originating from community inputs of individuals up to formal higher education institutes. The role of higher education institutes will change in the transition towards a circular economy. The Ellen MacArthur Foundation is currently working on what the role of higher education in shaping the future economy. 22 November the foundation will host a 1-day live conference about this topic, exploring together with their partner universities the landscape of education through a circular economy lens. Academics, students, teachers, businesses, and disrupters are all welcome to join this discussion and accelerate the transitions towards a circular economy.

# The Relative Importance of Aesthetics in the Adoption Process of Solar Panels in the Netherlands

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**Abstract:** This study focuses on the possible advantage of an aesthetic appeal on the adoption of photovoltaic (PV) cells and panels. During the last decade, we have seen an impressive rise of installed PV capacity in the form of crystalline silicon-based panels. At present times, these conventional panels are foremost delivered in a blue or black version that, according to potential buyers, may disturb the appearance of their houses. This perception of solar panels could hamper future market growth.

Our study deals with the importance of this perception of solar panels by potential buyers. It reports the relative importance of aesthetics compared with other attributes, namely investment costs, payback period, reliability and expected services as experienced by homeowners. It shows various consumer segments with different preferences about the adoption of solar panels. Consumers in the main segment value aesthetics the highest, where consumers in another important segment attach most value to a high service. In addition to that, our study shows that investment costs are relatively unimportant in the first stages of the adoption process of solar panels. Finally, a subsequent market simulation demonstrates market growth opportunities of nearly fifty percent for aesthetic alternative solar panels.

We conclude that the decision to adopt solar panels is determined by more factors than just the investment costs. These results are not in line with the general perception of the installers. They also partly contradict other studies on aesthetic applications versus investment costs of solar panels. A first exploration of reasons for this divergence hints at the importance of the different stages of the purchase process in which the respondents of the studies are located. Therefore, we recommend further study on the role of purchase stages in order to explain the adoption of solar panels.

## 1 Context: a new generations of solar panels

At present times, a growing number of roofs of houses are covered with solar panels but they are still greatly outnumbered by houses without these panels. Several reasons why homeowners do not choose for solar panels are: the price-level (W/E adviseurs, 2015), financial uncertainties about the payback of these solar panels (Motivaction, 2011) and the fact that panels are not considered as "nice-looking" (Ponte , 2015).

Many of the present solar modules are installed at existing tiles. We refer to them as "add-on modules". These modules offer only a small choice in size and color, namely blue or black. These standard dimensions of the solar panels cause problems when they cannot be fitted upon an individual roof. It is also difficult to affirm this add-on modules around a dormer or chimney. The Solar Trend Report 2014

(Solar Solutions, 2014) refers to one of the new trends, namely that consumers increasingly ask for aesthetic solutions. At the moment, several studies are conducted to integrate solar devices within a roof in order to reach an aesthetically superior roof. Other studies focus on flexible add-on modules with a wider color range or wider dimensional sizes and forms to attain the same aesthetic impact.

The goal of our study is to provide insight into the motives of customers to select innovative, aesthetic solar panels. What are their motives, and to what extent are they willing to pay extra for nice-looking solar panels? The use of the theory of acceptance processes may offer new insights to the relative importance of aesthetics in relation to other selection criteria of solar panels.

## 2 Attributes for the adoption of solar panels

This study applies a modified version of Unified Theory of Acceptance and Use of Technology (UTAUT2). The UTAUT2 model is effective in research on consumer behavior with regard to the acceptance of a new technology. So far, stakeholders in the solar and construction sectors, and in particular the installers, have the perception that the consumer is not willing to pay extra for a different option than the default modules; therefore they view more costly aesthetic variants as unattractive (W/E adviseurs, 2015; Ponte, 2015; Motivaction, 2015).

Previous consumer research (e.g. at mobile Internet devices) has revealed that more factors have an impact on the acceptance of a technology in addition to the expected performance and expected effort (Venkatesh et al., 2012). We apply the UTAUT2 model in order to verify the selection of solar panels amongst consumers. Hedonistic motivations are taken into account because we expect that they will affect behavioral intentions. In addition to that, price value is taken as a relevant factor for the purchase decisions of consumers with respect to technology. In order to measure the degree of the acceptance of solar panels, we introduce the following attributes that influence their choice.

### *2.1 Price*

The cost of purchasing a solar system is the first attribute that is extensively discussed in the literature (Sidiras & Koukias, 2004; Watson, Sauter, Bahaj, James Myers & Wing, 2006; Caird, Roy & Herring, 2008; Zhang, Shen and Chan, 2012). This includes the cost of PV panels, mounting hardware, circuit breakers, inverters and cables (Zhang, Shen and Chan, 2012). The various studies show that the high investment, or even the perception of consumers that solar is expensive, provides a barrier to the adoption of solar panels (Arkesteijn & Oerlemans, 2005).

### *2.2 Payback period*

The price is related to another frequently mentioned attribute, namely the payback period. This is the period between the moment of the investment until the moment this investment is recouped through revenues coming from this investment (Zhang, Shen and Chan, 2012). In general it is stated that, the higher the initial cost, the longer the payback period, assuming identical returns. This long payback is confirmed by several studies as a major barrier to the selection of solar panels (Sidiras & Koukios, 2004; Watson et al., 2006; Caird, Roy & Herring, 2008; Zhang, Shen & Chan, 2012).

### *2.3 Reliability of the performance of the system*

One of the technical issues for the (non-) selection of solar panels is the unknown reliability of the operation of the technology. Reliability refers to the annual number of incidents, defects or problems related to the installation. Proven cost-effective technologies such as renewable energy, are still seen as risky because there is little experience with such new applications (Beck & Martinot, 2009). Some studies (Watson et al., 2006; Caird, Roy & Herring, 2008; Mirza, Ahmad, Harijan and Majeed, 2009) have shown that this uncertainty about the reliability, caused by the lack of understanding of the systems and familiarity with the new form of energy, slows down the selection of solar cells.

### *2.4 Expected service*

Another issue that has a negative impact on the adoption is the uncertainty about finding a reliable installer (Caird, Roy & Herring, 2008) and lack of well-trained installers (Mirza et al., 2009). The lack of knowledge and information about the level of service may increase perceived uncertainties and so block decision-making (Beck & Martinot, 2009). This uncertainty also stretches to general provided services such as the reaction time to solve problems concerning PV installation.

### *2.5 Aesthetics*

If product alternatives are equal in functionality and price, consumers will choose the product which is the most attractive in aesthetic sense (Creusen & Schoormans, 2005). Our research applies the definition of aesthetics as "for the eye beautiful things, because they are in harmony with the environment and this makes it a pleasure to watch (Kootstra & van der Zwaal, 2006; Holbrook & Zirlin, 1985). The aesthetics of a product can result in significant influence on consumer behavior. An improved or innovative product appearance is  advantageous in certain commercial purposes, or for commercial products such as solar panels(Veryzer, 1993).

A number of studies have indicated that aesthetics is a key factor for the adoption of solar panels. One of these studies has concluded that the adoption rate of solar cells decreases if they negatively impact the visual landscape or appear too pushy (Faiers & Neame, 2006). Also Sidiras and Koukios (2004) indicate that the non-aesthetic character of the current solar panels is a barrier for their purchase.

People differ in their perception of beauty so that consumers differ in the degree of acceptance of an innovation based on aesthetics. (Kootstra & van der Zwaal, 2006). Especially the groups that are referred to as innovators and the early adopters, appreciate the appearance of the product and attach the most importance to aesthetics. This means that aesthetic design has a positive impact on the acceptance of a new product in these groups (Yamamoto & Lambert, 1994).

We conclude that, although price is an important decision-making criterion for the selection of solar panel, many attributes are seen in the literature as relevant. Therefore we design our method of study to assess the simultaneous impact of these attributes upon the adoption process of solar panels in order to find preferences of different groups of homeowners.

## 3 Method of study

Based on the literature and the pilot test, the items investment costs, payback period, aesthetics, reliability and expected services are expected to determine the choice of solar panels and are therefore included as attributes in a conjoint analysis. The purpose of a conjoint analysis is to find the relative importance of various product attributes (Green & Srinivasan, 1978). Conjoint analysis, and in particular the choice-based conjoint variant, is a useful method for the development of technical products such as solar panels (Van Kleef et al., 2005). We ask respondents to make trade-offs between more and less aesthetic solar panels (a pairwise comparison method). Each respondent receives eight choice sets and must, each time, choose between two (hypothetical) options. This choice set refers to a realistic product, that is a combination of the above-mentioned five product attributes. The scores for each attribute are shown in Table 1.

| **Attributes** | **Attribute level 1** | **Attribute level 2** |
|---|---|---|
| **Investment costs (per 30 m$^2$)** | Low costs *(€6000)* | High costs *(€9000)* |
| **Payback period** | Short period *(6 years)* | Long period *(9 years)* |
| **Aesthetic** | Low *(no match in shape and color)* | High *(match in shape and color)* |
| **Reliability** | Low reliability *(≥ 1incidents/failures per year)* | High reliability *(no incidents/failures per year)* |
| **Expected services** | Poor service *(slow, not clear and sometimes incorrect service)* | Good service *(rapid, transparent and accurate service)* |

**Table 1:** Attributes with associated attribute levels

We offer the respondents illustrative images of the roofs with solar panels (visuals) in the choice-sets. The conjoint analysis applies a convenience sampling technique to recruit the needed number of respondents with the condition that the respondent possesses a house with an own roof.

## 4 Results

In total, 231 respondents completed the survey. Of these 231 respondents, 213 persons have answered the question "do you own your home" positively. We continue our analyses with these 213 respondents. This number is within the range of 200 to 300 minimally required completed surveys, a regularly applied rule-of-thumb of the conjoint analysis, and sufficient for developing hypotheses about a market (Orme, 2010).

A three segment model (as shown in Table 2) was the best fit with the data as defined by the latent gold choice program. We describe these segments below.

| | **Segment 1 (40%)** | **%** | **Segment 2 (32%)** | **%** | **Segment 3 (28%)** | **%** |
|---|---|---|---|---|---|---|
| **Investment costs** | 0.0236 | 2% | 0.0965 | 10% | 0.0269 | 3% |
| **Payback period** | 0.0661 | 7% | 0.0432 | 4% | 0.1060 | 11% |
| **Aesthetics** | 0.5913 | 60% | 0.2048 | 20% | 0.0602 | 6% |
| **Reliability** | 0.1057 | 10% | 0.1579 | 16% | 0.1254 | 12% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Expected services** | 0.0874 | 9% | 0.1958 | 20% | 0.1647 | 16% |
| **No choice** | 0.1259 | 12% | 0.3018 | 30% | 0.5169 | 52% |

**Table 2:** Relative importance of the attributes by segment[1]

### *4.1 Segment 1: aesthetics caring consumers*

The major part of the consumers (40%) is classified as aesthetics caring consumer. Consumers in this segment value the aesthetics of solar panels as the highest selection criterion. Here, aesthetics is seen as the most important factor (60%), while the consumer favors in 96.2% of cases a high level of aesthetics. If it is not possible to select nice-looking solar panels, they will not choose solar at all.

### *4.2 Segment 2: choosy consumers*

It not very clear to what attribute the consumer in this segment (32%) attaches the most value. People in this segment find it important to be able to choose the "no choice" option, meaning that they do not prefer the different choice sets. This may also indicate that this segment is very picky.

### *4.3 Segment 3: consumers that prefer certainty*

Consumers in this segment (28%) prefer solar panels with a short payback period, high reliability and good service. They also attach high importance to the "no choice option" but the majority (98,7%) chooses, in the end, for solar panels.

Based on the profiles of these three segments we conclude that the consumers can be approached with an aesthetically shaped solar product with high service. It is realistic that the price is relatively higher and the payback period is relatively longer than those of the standard panels. This type of solar panel will have a lower reliability level due to its newness. This product is interesting for the aesthetic caring consumers because of its high aesthetic design, but also the consumer that prefer certainty will favor it because of its high level of service. We conduct a market simulation to verify the level of market growth by the introduction of the aesthetic solar panels.

### *4.4 Market simulations*

The first market analysis describes the current situation, where two options are compared: the "no choice" option versus the standard solar panels. Table 3 demonstrates that 51.3% would choose the standard panels.

| | | Segment 1 | Segment 2 | Segment 3 | Total |
|---|---|---|---|---|---|
| **Standard PV** | | 46,1% | 14,7% | 99,7% | 51,3% |
| | €6000 investment costs | | | | |
| | 6 year payback period | | | | |

[1] Table 2 shows three segments with their relative size and perceived importance of individual attributes such as reliability and so on as perceived by respondents. It does not reflect choices on their level (high-low, etcetera).

| | | | | | |
|---|---|---|---|---|---|
| **Standard PV** | | 46,1% | 14,7% | 99,7% | 51,3% |
| | €6000 investment costs<br>6 year payback period<br>Low aesthetics | | | | |

**Table 3**: Market simulation for standard solar panels, per segment and in total.

Table 4 shows the second market analysis with the "no-choice" option, the standard panels and the aesthetics solar panels, which are described with their corresponding properties. A high number of the consumers, namely 43.7%, would choose the new, aesthetic panels and 31.0% selects the standard panels (a total of 74.7%).

| | | Segment 1 | Segment 2 | Segment 3 | Total |
|---|---|---|---|---|---|
| **Standard PV** | | 9,2% | 11,4% | 83,9% | 31,0% |
| | €6000 investment costs<br>6 year payback period<br>Low aesthetics<br>High reliability<br>High expected services | | | | |
| **Aesthetics PV** | | 80,0% | 22,7% | 15,9% | 43,7% |
| | €9000 investment costs<br>9 year payback period<br>High aesthetics<br>Low reliability<br>High expected services | | | | |
| **No choice** | | 10,8% | 65,9% | 0,02% | 25,3% |

**Table 4**: Market simulation for standard solar panels and aesthetic solar panels, per segment and in total.

So, only 25.3% of the consumers do not choose panels at all, which is 50% less than the "no choice" consumers in the first market analysis. The aesthetics caring consumers choose this aesthetic option with a clear majority (80.0%). The choosy consumer still prefer the "no choice". Finally, the majority of the certainty consumers (83.9%) still prefers the standard panels, probably because of its high reliability. Summarizing, the introduction of the product offers a market growth for solar panels of 45.6% (((74.7% - 51.3%) / 51.3%) * 100 ).

## 5 Conclusions

Our study shows a surprisingly positive picture about the appreciation of aesthetics. Consumers of segment one experience a significant need for aesthetics. They state that aesthetics is an important attribute and choose for a high aesthetic variant. They even consider aesthetics as the key factor that determines their choice of innovative solar panels. The willingness to choose solar panels will be more positive if there is a high aesthetic option.

In segment two and three the importance of aesthetics is viewed as a less important feature, but when giving the possibility, consumers choose for the more aesthetic option – so these segments do not contradict the attention for aesthetic solar panels. Consumers in segments two can be characterized as picky. Their preference-level of all attributes is of an approximately equal size. The certainty preferring consumer in segment three values aesthetics as lowest attribute, compared with the other segments. This consumer determines his choice on the basis of the reliability and the expected service of the solar panels.

Some of our results contradict the attention for price and financial returns as main buying criteria for solar panels, which is found in previous studies (Motivaction 2015; Ponte in 2015 with reference to Stolks/MilieuCentraal 2014). A recent study shows that installers assume that consumers tend to choose for the lowest price and also are not willing to pay more for another, more aesthetic form of solar panels (W/E adviseurs, 2015). However, we have shown that the choice to select solar panels depends on more factors than their price only. Our conclusion is contrary to this idea of installers. A reason for this difference may be that the several studies (W/E adviseurs, 2015 Ponte; 2015; Motivaction, 2015) and our study are in different stages of the buying process. Our study, for instance, focuses on the awareness stage for the AIDA model and not the use behavior stage of the UTAUT2 model that refers to the actions AIDA action stage. The impact of aesthetics becomes particularly evident in the market simulations that demonstrate a 45.6% market growth when factors such as aesthetics and service are given attention to. We suggest to inform installers that there are different consumer needs; an expansion of the variety of the supply of solar panels while addresses the various needs of consumers, may result in a larger market.

Based on these market opportunities, we recommend further study on the importance of the stages, in which the potential buyers are located, for the weighing of the various buying criteria. Especially the impact of the provision of specific providing decision-making information to the possible consumers of different segments in the different stages of the buying making process, could shed more light on the better adoption of various types of solar panels.

This study has some limitations. As stated before, the results of the conjoint analysis may differ from real purchase decisions. The choice sets for the respondents are a simplification of the reality. Besides, respondents may not take all attributes and attribute levels into account for his decision. We have tried to avoid this by not including many attributes in the choice sets. Furthermore we have not linked demographic data such as income class with the three segments. Another limitation is that the conjoint analysis contains pictures of roofs with solar panels. This usage of visuals may distract the attention from the verbal information too much, leading to a situation where a respondent selects a particular option because of the preference for the image instead an objectively evaluation of the product. (Couper, Tourangeau & Kenyon, 2004). We suggest a follow-up study to perform a more extensive pre-test of the images in order to determine whether these images are considered as equally attractive.

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# Building Capacities for Sustainable Energy in Municipalities of Western Balkans

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## Abstract

This paper discusses challenges of capacity building in sustainable urban energy planning and development in Western Balkan Countries (WBC). It identifies needs in training of municipal staff and addresses obstacles for transferring sustainable energy education from EU universities to universities of WBC. The analysis of the ten training courses developed and piloted in collaboration with academic and non-academic stakeholders in Bosnia and Herzegovina, Montenegro and Serbia shows that while international cooperation has a good potential to improve quality of capacity building and to catalyse university-society collaboration in WBC, significant efforts on national and local (university) levels are needed to fully capitalise on these opportunities. In particular, it is necessary to enhance an interdisciplinary approach to education in sustainable energy, incorporating economic, social and institutional aspects of energy production and consumption together with the technical ones. On the national level, the lifelong learning system should get political and financial support in WBC to ensure efficiency and continuity of the training activities.

## 1 Introduction

The transition to a sustainable energy system is essential for reaching Sustainable Development Goals (SDGs) adopted by the world leaders at the United Nations Sustainable Development Summit in 2015. While *Affordable and Clean Energy* is highlighted as one of these goals, energy issues are central for achieving the whole set of SDGs to end poverty, fight inequality and injustice, and tackle climate change by 2030. Correspondingly, reliability and efficiency of the energy infrastructures are recognised as crucial factors for the quality of life and sustainable economic growth in the Western Balkan Countries (WBC[1]) (International Energy Agency, 2008).

Knowledge, education and the capacity to develop new knowledge is of primary importance for sustainabilising energy systems (Hekkert et al., 2011). The knowledge that is required is not just the knowledge to develop new generic technological systems, but especially the knowledge to pick the right energy systems for the local conditions, and to use these conditions optimally to sustainabilise the pre-existing energy systems. Both the geophysical conditions as well as the economic and cultural local conditions are important. Hence, training local decision makers on and operators of energy systems is of great importance (Lalic et al., 2011).

A number of programs for development of sustainable energy infrastructures were implemented in the WBC since the EU Instrument for Pre-Accession Assistance (IPA) had been launched in 2007. Enhanced capacity of public authorities in energy efficiency, energy infrastructure, renewable energy and environmental protection were among the expected outcomes of these programs. However, local authorities in WBC are still lacking knowledge and skills necessary for making both operational and strategic decisions on sustainable energy, which in several cases led to ironic consequences when municipalities failed to use technical assistance funds due to inability to formulate applications for so needed infrastructure projects (Anger, 2012).

The underlying problem is twofold: on one hand, the lifelong learning system is underdeveloped in WBC; on the other hand, the intensive training courses by foreign experts have a number of limitations, such as a) neglecting the local context and differences between existing practices and procedures in EU and WBC; b) language barrier; c) prevailing one-way lecturing; d) limited possibility for after-training support and networking with the trainers; and e) high cost.

One of the ways to overcome the problem is establishing training activities by local actors, in particular, local universities, which in turn is a challenging task as WBC universities as a rule have rather limited experience in collaborative projects with municipalities, industries and other non-academic stakeholders. While knowledge transfer from experienced universities has a potential to meet this challenge, the simple copying of training curricula would fail to reflect the local conditions both in terms of required knowledge and skills, and in terms of institutional capacity of local universities to provide the trainings. Thus, it is necessary to adapt international experiences to needs, expectations and constraints of both local trainees and trainers.

In this study we attempt to bridge a gap in understanding of needs for capacity building in sustainable urban energy planning and development in WBC, and to investigate obstacles for transferring sustainable energy education from EU universities to local universities.

## 2 Approach and Methods

This study is based on findings of the EU-funded project "Training Courses for Public Services in Sustainable Infrastructure Development in Western Balkans" that was conducted in 2012-2015 by the project consortium consisting of universities from EU, Bosnia and Herzegovina, Montenegro and Serbia and the society partners - associations of local authorities that represented municipalities of the partner countries (e.g. Association of Municipalities and Towns of Republic Srpska, Bosnia and Herzegovina; The Union of Municipalities of Montenegro; and The Association of Towns and

[1] Hereinafter we mean Albania, Bosnia and Herzegovina, Croatia, Former Yugoslav Republic of Macedonia, Montenegro, Serbia, and Kosovo under UN administration

Municipalities of Serbia). The project addressed the regional needs in capacity building required for development of the energy infrastructures in WBC, focusing on three priority areas: 1) Sustainable Urban Development; 2) Sustainable Energy Infrastructure; and 3) Good Governance. The project resulted in development and implementation of ten training courses in the selected topics relevant to the aforementioned priority areas. More than 300 stakeholders have been retrained during the training program. Besides, 33 teachers and 13 representatives of local authorities have been retrained at EU Universities.

While generalisability cannot be claimed by this case study, its conclusions can be of interest for capacity building activities in the whole region. This is mainly because of three reasons: firstly, due to geographical and historical similarity, WBC share many common challenges regarding their energy systems. According to International Energy Agency (2008), the core elements of the energy infrastructure in the region were built in the 1960s and 1970s using standard low energy efficient technology. The age and poor maintenance of the energy infrastructure during the 1990s cause an urgent need for renovation or replacement. Besides, Western Balkans have strong dependence on imported hydrocarbon fuels (though, there are substantial differences between the countries in energy mix and dependence on energy import). To overcome these challenges, all countries in the region launched energy reforms with capacity building as an important enabler of transition to more sustainable energy systems. Secondly, participation of associations of local authorities in the project countries or their parts (e.g. Serbia; Montenegro; and Republic Srpska, Bosnia and Herzegovina) allowed us to get insights into problems, needs and potentials, shared by large number of municipalities in the region. Thirdly, the project involved leading universities in the partner countries, which makes it highly probable that the challenges and barriers experienced by them would be relevant for many other Universities in the region.

## *2.1 Research design*

The empirical data of this study were collected and analysed within all three stages of the SDTRAIN project, namely pre-project assessment, planning of the training courses, and implementation and evaluation of the courses. The overall research design is presented in Table 1.

The main methods used included interviews with teachers, representatives of associations of municipalities, representatives of funding agencies and trainees; literature review (predominantly energy- and capacity building- related reports for WBC); observation of the training activities; and analysis of the project outcomes (e.g. number of trainees, coverage of the training topics, unexpected spin-offs etc). The Consensus Dynamic Workshop and Delphi survey were used for needs analysis as presented in the Section 2.2.

Table 1: Research design

| Stages | Activities | Involved stakeholders |
|---|---|---|
| I. Pre-project assessment | – literature review<br>– interviews | – teachers<br>– representatives of associations of municipalities<br>– representatives of funding agencies |
| II. Planning of the courses | – literature review<br>– survey<br>– Consensus Dynamic Workshop | – Teachers<br>– representatives of associations of municipalities |

| | | | |
|---|---|---|---|
| | | – Delphi survey | |
| III. | Implementation & evaluation of the courses | – observation of the training activities<br>– interviews<br>– analysis of the project outcomes | – teachers<br>– representatives of associations of municipalities<br>– trainees |

### *2.2 Methods of needs analysis*

The needs analysis was performed using a participatory approach with involvement of all local authorities participated in the project. It was organised in three steps:

First, a *Preliminary Survey*: simple questions to gather views of the participants on the tree areas of interest (Sustainable urban development, Sustainable energy infrastructure and Good governance).

Second, a *Consensus Dynamic Workshop* (1.5 hours): based on the preliminary survey, the group brings together the results, identifies areas of agreement and seeks agreed definitions, and prioritizes keywords. The session was structured as follows:

- Presentation of first results on keywords from the preliminary survey;
- Collective definition of keywords;
- Work in groups: filling in the missing concepts;
- Sharing ideas;
- Voting for keywords.

And finally, *Post-workshop Delphi survey* (Hasson et al., 2000) aiming to collect the priorities of the partners on:

a) What their needs are and how they are covered by the outputs of the process;

b) What the target destination of training courses is;

c) What the universities should certify and how this certification is to be recognized.

## 3 Results

### *3.1 Identified needs*

From the preliminary survey (see Section 2.2) the trainees' profile was identified as:

- Engineering, architecture, economics and law education background;
- Long experience in local governments;
- Diverse professional profiles;
- Different levels of responsibility;
- Interested in sustainability (voluntary participation);
- Have training / knowledge in energy management and energy efficiency;
- Special interest in studying in depth sustainable urban development (SUD) and good governance.

In relation to the three areas of interest, the main training demands/needs are clustered in Table 2.

Table 2: List of the keywords relevant to the three areas of interest identified through group consensus

| | Sustainable Urban Development | Sustainable Energy Infrastructure | Good Governance |
|---|---|---|---|
| Knowledge & understanding | Sustainable infrastructures<br>Energy efficiency and water supply<br>Low energy consumption<br>Mobility<br>Local energy production<br>Sustainable indicators expertise<br>Innovation<br>Social development<br>Individual welfare<br>Resilience<br>Environmentally friendly | Supply security<br>Transport and Buildings<br>Environmental & Social impacts<br>Waste management<br>Local distribution networks<br>Waste-to-energy<br>New tech / smart grids / RES<br>Efficiency<br>Functional (effective and flexible)<br>Policy and regulations | Corruption<br>Transparency / control<br>Information / awareness rising / change behavior<br>Best practices / Models<br>Public Private partnerships |
| Instrumental competences | Integrated approach: building, development, growth<br>Communication<br>Lifelong learning<br>Teamwork | Planning<br>Lifelong learning | Long term thinking<br>Multidisciplinary approach<br>Strategic planning on national and local levels |
| Required processes | Integration of SUD in strategic municipality plans<br>Sharing knowledge, exchanging experience<br>Good interdisciplinary cooperation | | Good communication from government and municipalities<br>Build trust and support from stakeholders<br>Participation of civil society<br>Help low income and vulnerable people |

Trainees expressed interest in training related to different phases of planning and implementation processes (policy design, territory planning, infrastructure development and awareness-raising) with special emphasis on awareness-raising programs. The following needs were explicitly stated:

- To learn how to develop strategic energy plans and to implement projects on energy infrastructure development;
- To prepare concrete energy efficiency projects;
- To understand the “true meaning” of sustainable development;
- To implement awareness-raising programs among population;
- To transform global policies into local strategic plans.

According to trainees, the courses should encompass the following topics: social dimension of sustainability; examples and best practices in sustainable local management and local management transparency; social innovation processes. Further, the courses should provide cross-cutting competences on team working and communication tools; and tools that facilitate stakeholders/civil society participation in decision-making.

Finally, the trainees specifically asked for combining theoretical and practical teaching methods. According to them, the theoretical foundations are necessary in order to consolidate individual visions on sustainability, especially on the social dimension of the sustainability concept. The practical part is needed in order to understand the process dynamics. It should allow the participants to transfer their acquired knowledge to their working environment.

Following the needs analysis, ten courses were designed and piloted in collaboration of WBC and EU universities taking into consideration the identified needs and expertise of partner universities. The overview of the courses is provided in Table 3.

Table 3: Training courses

| Course title | Implementing universities | Where and when the course was piloted | Setup of the pilot course |
|---|---|---|---|
| *Sustainable indicators for municipalities* | University of Belgrade<br>UPC | Niš, Serbia<br>December 3, 2013<br>March 20, 2014 | 2 full-day workshops<br>• lectures<br>• practical work in Moodle in between |
| *Energy system analysis* | University of Kragujevac<br>TU Delft | Kragujevac, Serbia<br>December 6, 2013 | 1 full-day workshop<br>• lectures<br>• individual tasks |
| *Renewable energy* | University of East Sarajevo<br>University of Banja Luka | East Sarajevo, Bosnia and Herzegovina<br>December 16, 2013 | 1 full-day workshop<br>• lectures<br>• individual tasks |
| *Energy efficiency in public buildings* | University of Montenegro | Podgoritsa, Montenegro<br>February 5, 2014 | 1 full-day workshop<br>• lectures<br>• group work<br>• practical modules in Moodle |
| *Participatory backcasting for the city heating system* | University of Belgrade<br>University of Kragujevac<br>KTH | Niš, Serbia<br>April 4, 2014 – June 27, 2014 – February 20, 2015 | 3 full-day workshops<br>• lectures<br>• group work<br>• group presentations |
| *Energy efficient renovation and retrofitting approach* | University of Belgrade | Kula, Serbia<br>February 4, 2014<br>July 2, 2014 | 2 full-day workshops<br>• lectures<br>• practical work in Moodle in between |
| *Energy planning, methodologies and tools* | University of Kragujevac<br>KTH | Kragujevac, Serbia<br>December 6, 2013<br>June 6, 2014 | 1 full-day workshop<br>• lectures<br>• individual tasks |
| *Scenario methods in energy planning for local communities. Planning of new urban areas for local communities* | University of Banja Luka<br>University of East Sarajevo | Banja Luka, Bosnia and Herzegovina<br>June 30, 2014 | 1 full-day workshop<br>• lectures<br>• group work |
| *Development of sustainable energy infrastructure* | University of Banja Luka<br>University of East Sarajevo | Jahorina, Bosnia and Herzegovina<br>December 4, 2014 | 1 full-day workshop<br>• lectures<br>• group work<br>• preliminary tasks in Moodle |
| *Renewable energy management* | University of Montenegro | Podgoritsa, Montenegro<br>October 10, 2014 | 1 full-day workshop<br>• lectures<br>• group work |

## *3.2 Identified barriers*

The barriers for capacity building and obstacles for transferring sustainable energy education from EU universities to universities of WBC were identified through analysis of the training needs that have not been met by the developed courses, and through interviews with trainers and trainees.

Analysis of the keywords that were not fully addressed by the developed courses (see Table 4) shows that the vast majority of the keywords related to technology-related knowledge and skills was covered by the developed courses. The only exceptions were transport and waste topics that were excluded mainly due to the project limitations (e.g. time and budget). At the same time, the economic, institutional and social topics as well as some 'soft' skills were only partly or superficially addressed. Obviously, the lack of experiences in multidisciplinary and interdisciplinary education and research at Engineering Faculties of partner universities was one of the reasons for this shortcoming. Despite this issue being discussed from the beginning of the project, introduction of multidisciplinary approach to energy education and training remains a challenge to address in WBC.

Table 4: Keywords that were not fully addressed by the developed courses

| | **Sustainable Urban Development** | **Sustainable Energy Infrastructure** | **Good Governance** |
|---|---|---|---|
| Knowledge & understanding | *Mobility*<br>Innovation<br>Social development<br>Individual welfare<br>Resilience | *Transport*<br>Social impacts<br>*Waste management*<br>*Waste-to-energy* | Corruption<br>Transparency / control<br>Public Private partnerships |
| Instrumental competences | Communication<br>Teamwork | | Multidisciplinary approach |
| Required processes | Good interdisciplinary cooperation | | Good communication from government and municipalities<br>Participation of civil society<br>Help low income and vulnerable people |

The pre- and post-interviews with teachers, representatives of associations of municipalities and other local stakeholders revealed two more barriers:

- The lack of university-industry-society collaboration was often named as one of the main causes of a mismatch between supply and demand of capacity building activities;
- The underdeveloped lifelong learning system in WBC leads to discontinuity and, in-long run, inefficiency of the training activities.

Finally, the interviews with teachers and trainees as well as observations during the courses revealed that majority of trainers and trainees did not consider themselves as change agents and were pessimistic about their ability to change the system of training and the system of energy planning respectively. This could be partly explained by hierarchical mode of decision-making and strategic planning; week local self-governance; and prevailing short-term thinking in WBC.

## 4 Discussion and conclusion

This study highlights challenges of capacity building in sustainable urban energy planning and development in WBC and addresses needs and barriers in training of municipal staff in the region. The study concludes that the international cooperation has a good potential to improve quality of capacity building and to catalyse university-society collaboration in WBC; however, to reach these effects, the international experiences should be adapted to local needs and constraints. Saying this, the adaptation to local conditions does not mean uncritical application of teaching practices prevailing in WBC. On the contrary, the knowledge transfer through training of trainers should include modern problem-based teaching methods to deliver the high quality of stakeholder training. For instance, the best learning outcomes within the SDTRAIN project were observed during a participatory backcasting course in Nis, which can be partly explained by an extensive learning-by-doing process and the highest level of motivation among both trainers and trainees due to the real-life nature of the problem addressed within the course; as well as by multidisciplinary mode of the course.

Finally, analysis of the pre- and post-project interviews with the local trainers and trainees and the project's unexpected spin-offs (e.g. collaboration agreements between universities and associations of municipalities; the letter of commitment by the Mayor of Nis to use outcomes of the SDTRAIN project in the strategic development of the city's heating system; a new backcasting project initiated by trained staff of a local University in municipality of Ivanjica (Western Serbia), etc.) showed that despite the identified barriers, the training courses allowed: a) acquiring contextualized knowledge and practice-oriented skills; b) developing strong network of stakeholders capable to facilitate sustainable infrastructure development; and c) advancing research agenda at the local universities through their linkage with societal actors and orientation towards solving societal challenges. However, the SDTRAIN project bears the risk of becoming a one-time experiment if establishing the lifelong learning system in WBC would not get political and financial support from the national governments.

## Acknowledgments

Authors express their gratitude to the representatives of the national associations of local municipalities - Mr. Predrag Pajić (Association of Local authorities of Republic of Srpska, Bosnia and Herzegovina), Mr. Saša Šćekić (Union of Municipalities, Montenegro) and Mr. Bojan Gajić (Standing Conference of Towns and Municipalities, Serbia) for providing the authors with valuable information, and to all trainees who participated in the SDTRAIN courses and workshops, and contributed to development of the results presented here.

This study was supported by the SDTRAIN project funded by the European Union's Tempus Programme under grant agreement no. 2012-3006.

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# Introducing regenerative design and circularity into architectural and engineering curriculum

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**Abstract**

Looking today to the challenges for planning and design of sustainable built environment including, carbon emissions, climate change, human health, water problems, biodiversity, scarcity of resources, depletion of fossil fuel, population growth and urbanization; sustainable architecture will play a key role for the sustainable development of society as a whole. In the context of an architectural design studio, this paper presents the experience of introducing the concept of regenerative design within a Belgian engineering faculty. The regenerative design objective and principles are used as a method to develop engineers' capabilities to design within a circular economy paradigm. The aim of the study is to evaluate the adoption of circular economy principles and their influence on the decision making and final outcomes on third-year architectural engineering students at the University of Liege (Ulg), Faculty of Applied Sciences in 2014 and 2015. The paper utilizes two design studios outcomes in the form of projects evaluation and students feedback, in the form of interviews and surveys, in order to assess the students' knowledge uptake, learned skills and design capabilities. Students completed a knowledge, skills, and attitudes questionnaire before the curriculum, after the final learning experience, and one year later. The paper provides results that shed light on the opportunities, challenges and architectural engineer's needs to engage in a circular built environment.

## 1 Introduction

The radical changes necessary for our planet require a vision that is rooted within an ecological paradigm. The tendency of urban sprawl and resource intensive built environment during the last decennia is contradicting with the need for positive impact development and the principles of sustainability. The urban sprawl is not only consuming large areas of land but is associated with negative environmental impacts, social and cultural disparities beside the overall decreasing incremental environmental cost.

In order to face these challenges the architectural design studio of the third year architectural engineering students at Liege University (Ulg) is playing a central role for challenging its students to generate a built environment that is dense, accessible by public transport, and based on positive impact buildings and sustainable construction technologies, following the principles of circular economy and regenerative design for a collective housing project in Belgium. The key question of the studio is: How can architects construct buildings with positive impact for the environment while addressing the materials, energy, water and biodiversity challenges.

In this context, the study aims to assess the students' learning experience using qualitative and quantitative evaluation methods. The importance of this study is significantly highlighted in the studio's ability to achieve an informed decision making process regarding regenerative design and circularly in the built environment. Secondary, the study provides a reflection on the assessment of learning outcomes, expected knowledge, skills, attitudes, competencies and habits that student acquired during the studio's learning process. With its focus on the design experience and knowledge uptake this article will be of interest to engineers, architects, educators and researchers concerned with engineering education of sustainable development (EESD). The article determines the needs for pedagogical and educational project oriented engagement to ascertain and quantify the effort needed to understand and apply those sustainability principles in future curricula. This paper is organized into five sections. The first section identifies the research topic. The second describes similar studios and courses that have been presented at previous EESD conferences aiming to describe the state of the art. The third section identifies the research methods and studio evaluation metrics and setting. The analysis of the results and the self-reported survey and questionnaires findings are presented in Section 4. The final section discusses the research finding and study limitations along with implications for future teaching and education.

## 2 State of the Art

### *2.1 Past research*

There is an extensive body of literature examining the effects of introducing sustainability in the engineering curricula on the students' knowledge and skills and final learning outcomes. The international conference on Engineering Education in Sustainable Development (EESD) proceedings include several examples of integrating sustainable principles as a framework for a redesign of engineering education and of engineering education institutions. Also the International Journal of Sustainability in Higher Education and the Journal of Architectural Education provide a series of valuable publications related to introducing sustainability into engineering curricula. In the local Belgian context we looked in the Proceedings of the Doctoral Seminar on Sustainability Research in the Built Environment (DS2BE 2016). Three screening criteria were used to reduce the initial pool of 60 conference and journal articles to a focused set of 15 representative studies: (a) review articles; (b) empirical studies (c) studies with an educational assessment or intervention with learner outcomes measured quantitatively or quantitatively; and (c) research that focus on architectural and engineering curricula due to the specific nature of our architectural engineering students.

Under the review articles we grouped the manuscripts under two groups. The first group is focused on integrating sustainability into engineering curriculum and second group is focused on integrating sustainability into architectural engineering curriculum. The first group of manuscripts include the study of Davidson et al. (2014) that discussed some efforts taken place in the United States, namely the activities of the Centre for Sustainable Engineering operated by a consortium of universities. The paper describes an initiative to develop a community oriented platform to serve as a repository for educational materials. Similarly McPherson et al. (2015) compared engineering programs in Canada and review and analysed the sustainability integration in curricula but with a focus on sustainable energy. The undergraduate programs reviewed by the authors were classified as conventional engineering programs with a sustainability add-on courses and did not embed sustainability fully in the curricula. Likewise, the study of Vargas, L. et al (2015) reported embedding sustainability in the curriculum of engineering school but only for the University of Chile.

The second group of manuscripts has an architectural focus including the work of Álvarez et al. (2016) who compared the presence of sustainability in architectural education is Asia with a focus on professional degree curricula. The study provided an overview of 20 selected influential schools in 11 countries according to contents, intensity and teaching modalities. Sustainability design studios received a special attention by the study and were examined against the three sustainability areas of ecology, society and economy. The study provided qualitative and compared the curricula without describing their sustainability thematic content in detail. Similar to this study is the study of Olweny (2013) who investigated the presence of environmental sustainable design and energy efficiency in architecture education in East Africa. His study highlighted the basic integration of sustainability with at least one course in the studies curricula and the need for more integration efforts. Moreover, Wright (2003) provided a brief review on introducing sustainability into the architecture curriculum in the United States. The paper is out-dated and focused on the integration of sustainability in architectural programs. However, the publication of Iulo et al. (2013) provided an interesting overview of six architecture programs in the United States considered to be leaders in sustainability education. The study findings highlighted consistent approaches to promote sustainability core values to undergraduate architectural education by supporting courses fulfil needs for sustainable education and encourage students' choice and specialization to sustainable design.

The most important manuscripts in this group are the COTE and EDUCATE reports. The Committee on the Environment (COTE), which serves as the community and voice on behalf of AIA architects regarding sustainable design works, together with the Association for the Advancement of Sustainability in Higher Education (AASHE) provides a more recent assessment of the state of ecological literacy and the teaching of sustainable design in architecture education as part of a proposal for a large-scale, long-term effort, led by the AIA COTE, to inject ecological literacy and sustainability principles into architecture education in the United States. The COTE mapped the strengths and gaps in teaching methodologies and identified top ten measures of a definition of sustainable design that are developed as a framework for different types of courses and studios. COTE reported that at many architecture schools, the mentor model is still firmly in place; students are "filled up" by the knowledge of a professor. The report (2006) indicate the use of other teaching modalities involving multidisciplinary, participatory, iterative, designing for place, designing across time and involving students to become more involved in framing the questions, shaping courses, and interacting with practitioners and in the community. Also a similar project took place in Europe in 2009, where Altamonte (2009) investigated environmental design in University Curricula and Architectural training in Europe. The European review identified mainly the status quo of integrating sustainability across most European member states and encouraged the holistic approach to architecture education (Attia 2010ab).

## 3 Method

### *3.1 Curriculum design*

The first three year Bachelor curriculum of architectural engineers of the Faculty of Applied Sciences of Liege University are built around project-based learning cases but also include basic science lectures and an introduction to engineering courses. The Bachelor Program curriculum focuses on developing students' architectural design skills, increasing their understanding of architecture and construction and introducing technical issues. The program is divided into 6 blocks over three years and covers architectural design methodology I-III, sustainable building construction technology I-III, History of Architecture, Graphical Composition, Architectural Studio I-III, Chemistry I-II, Calculus, Algebra, Physics I-II, English, History of Urban Planning, Computer programing, Fluid Mechanics, Building Materials, Solid Mechanics, Geology, Heat transfer, Structural Design, Project management, Structural Engineering, Metallic Structures, Statistics and probability, Thermodynamics and heat engines, Geotechnics and infrastructure (Architectural Engineering 2016).

We identified opportunity for introducing regenerative design and principles of circular economy in the Architectural Studio III. The Architectural Studio III was chosen because of the maturation of the students and the need to develop and crystalize the fundamental knowledge and skills through an integrated project. The existing curriculum was based on introducing a design project of middle sized housing in the third year and we found that it could be linked with a new content. The studio's curricular goals and learning objectives focus on analysing issues specific for the transformation of a European post-industrial city from a perspective of circularity. The studio focused on developing third year students' knowledge, skills, and attitudes relevant to regenerative design and circularity of the built environment. Several references guided our development of the studio curriculum. A body of literature informed students about the regenerative design and circularity in the built environment (Lyle, J. 1996, McDonough, et al. 2010, McDonough, W. et al. 2013, Mulhall, D., et al. 2010 and Rifkin, J. 2008). We implemented and taught the curriculum, which was approximately 4 ECTS equivalent to 120 hours in the fall of 2014 and 2015. The curriculum was taught by the author and a teaching assistant, with the assistance of volunteer jury members and guests for the site visits, role playing based debate, jury panel and small discussion groups.

The studio content addressed seven main themes listed and described in Table 1. The activities in this design studio were a synergy between sustainability and regenerative design theory and their integration in an architectural design project. This approach allowed us to address issues of conceptual coherence, spatial and expressive design while exploring simultaneously the possibilities for sustainability as an essential element for the design; which will become an important and essential task in the field of architecture. The studio focused in particular on studying the interaction between questions of density, mixed functions, quality of life in buildings, while in the meantime integrating the principles of bioclimatic architecture. This included the development of construction details in accordance with a basic understanding of sustainable buildings concerning energy, water and materials. The project design case was based on a study of solutions adapted on the development of plus energy and Passive House complying collective housing cluster. Solutions are successively developed throughout the different scales from the urban form, the ensemble of buildings, the building itself its envelope and materials.

Table 1: Regenerative design and circularity in the built environment curricular content and educational modality by theme, Liege University, Faculty of Applied Sciences, 2014-2015.

| Theme | Content | Educational Modality |
|---|---|---|
| Theory and Principles | Sustainable architecture and regenerative design | Lectures |
| | Bioclimatic design and Passive House Standard | Lectures |
| | Human well-being and quality of life | Lectures |
| | Construction systems and materials | Lectures |
| | Energy conservation and production | Lectures |
| | Water management + Biodiversity and air quality | Lectures |
| Philosophy | Cradle to cradle: Remaking the way we make things | Reading |
| Case Studies | Wijk van Morgen (Heerlen), Park 2020 (Amsterdam) | Site Visit |
| Reasoning | 1. How far to go with technology? | Debate |
| | 2. So where should be set targeted minimum performance? | + |
| | 3. To certify or not sustainable buildings? | Role Playing |
| Application | Concept development follow up (weekly) | Table Critiques |
| Assessment | Evaluating the design and project dynamics | Pre-Jury |
| | Provide individual Feedback | Panel Discussion |
| | Support and motivation for creation and design development | |
| Evaluation | Evaluating the design and project dynamics | Jury |
| | Provide individual Feedback | Panel Discussion |

## *3.2 Assessment of students' knowledge, skills, and attitudes*

We developed a 15-item questionnaire to evaluate the impact of sustainability of the curriculum on architectural students' knowledge, skills, and attitudes. Item development was informed by our literature review. The questionnaire included items modified from existing questionnaires assessing i) the knowledge concerning regenerative design, ii) the decision-making attitude and behaviour (reactions to design uncertainties), the jury evaluation, as well as items based on our curricular learning objectives. We selected items for the questionnaire based on the like hood that they would demonstrate change after students participated in our studio. Five multiple-choice items assessed students' knowledge, five items measured their comfort with skills (using a five-point ordinal scale where 1 = very uncomfortable and 5 = very comfortable), and 18 items measures attitudes (using a five-point ordinal scale of agreement with statement where 1 = strongly disagree and 5 = strongly agree). Based on our experience from a previous research (Attia 2013) we pilot tested the questionnaire for comprehensibility with second-year architectural engineering students and for applicability with one Master student with prior involvement with regenerative design.

### *3.3 Assessment of students' self-reported behaviours*

On the one-year post-test, we also asked students to report their behaviours since completing the curriculum. Students responded 'yes' or 'no' to items about whether they used what they learned in the curriculum, design errors, and disclosure and reporting experiences. We calculated the percentage of students responding 'yes' to each item.

### *3.4 Curriculum Evaluation*

We developed studio evaluations to measure students' reactions to the curriculum. Student used five-point ordinal scale to rate how well the curriculum met learning objectives, its usefulness in their architectural education, its future benefit to their architectural career, and if it should be continued. We also invited students to describe the most important thing they gained from the curriculum and to offer suggestions for improvements.

## 4 Results

### *4.1 Assessment of students' knowledge, skills, and attitudes*

36 students answered the questionnaires before and after the studio. Our analysis of paired comparisons of pre-test to post-test was based on these responses. No students indicated that they had had prior experiences with regenerative design or circularity in the built environment. These results can be divided into three categories: students' responses with improvement, those without change, and those with change in an undesired direction.

### *4.2 Responses with improvement*

Table 2 presents the pre-test means, mean paired differences, and confidence intervals for items with improvement both immediately after students participated in the curriculum (pre-test to post-test). Students' responses to one attitude item addressing the inevitability of regenerative paradigm, another about the effectiveness of this approach to create a positive impact versus the efficiency paradigm, and a third reflecting perceptions about competence and design errors improved immediately after attending the studio. These improvements were sustained after the studio. Four skills items also improved immediately after students took the curriculum: supporting a peer involved in a design error, analysing root causes of an error, accurately estimating the building energy consumption and generation, and disclosing an disclosing an error to a professor or assistant. Although not improving immediately, students' responses to one attitude item about architects routinely admitting and sharing information about errors and their causes improved at one year. Students' responses to an additional attitude item on the effectiveness of design errors, as well as the composite knowledge score, improved immediately following the curriculum, but these changes were not sustained at one year.

Table 2: Questionnaire items with improvement

| Item | Mean Change (95% CI) | | |
|---|---|---|---|
| | Pre-Test mean response | Post-Test mean response | Post-Test after Two-Years |
| **Attitude Questions*** | | | |
| Making errors in design is inevitable | 68.75 | 31.25 | 21.5 |
| After an error occurs, an effective design strategy is to work harder to be more careful | 62.5 | 65 | 61 |
| Competent architects do not design errors that lead to quality decrease | 6.25 | 25.5 | 22.1 |
| Architects routinely share information about design errors and what caused them | 12.5 | 56.2 | 53 |
| Design assessment types (weekly meeting with professor, debate, jury) do little to reduce future errors | 16.25 | 3.0 | 4 |
| **Skills Questions**** | | | |
| Supporting and advising peer who must decide how to respond to a design error | 18.5 | 72 | 66 |
| Analyzing a design to find the cause of a error | 50 | 48 | 45 |
| Defend the design successfully in a design assessment | 31 | 56 | 33 |
| Disclosing a design error to a professor | 81.25 | 12.50 | 8.5 |
| **Knowledge Items** | | | |
| Knowledge uptake score | 37.5 | 74.5 | 61 |

* Scale: 1 strongly disagree, 2 = disagree 3 = neutral, 4 = agree, 5 = strongly agree

** Scale: 1 very uncomfortable, 2 = uncomfortable, 3 = neutral, 4 = comfortable, 5 very comfortable

### *4.3 Curriculum Evaluation*

At the completion of the curriculum, 31 (86%) of students agreed that the studio content improved their ability to meet the learning objectives either well or very well. Eighty-five percent, on average, agreed strongly that the curriculum and learning modalities were useful in their architectural education. Ninty-two percent, on average, agreed or strongly agreed that the curriculum would be of benefit to their future career, and on average 78% recommended that the curriculum be continued for future architectural school classes. Topic mentioned as the most important thing students gained from the curriculum were an understanding that everyone makes design errors, how to address those errors at the root cause, and the mistake reporting and disclosure are important. Suggested improvements included changes in the timing of the curriculum, shorter sessions, less lecture, more personal follow up sessions, more feedback and more guidance on communication issues.

## 5 Discussion and Conclusion

All members of the engineering academic world, including architectural engineers, should be able to recognize the importance of applying the regenerative design and circularity concept in their curricula. Students should be able to systematically apply those concepts and principles in a project oriented format with a thorough understanding of students problem solving and creativity skills. Our results demonstrate regenerative design and circularity in the built environment curriculum was well received and led to some changes in third-year architectural engineering students 'knowledge, skills, and attitudes. However, not all of these changes were for the better, nor were all of the positive changes sustained after the design studio or supported by students' self-reported behaviours on the long term.

We believe there are several sets of factors that contributed to these results. The first is the curriculum itself, including the course content, instructor effectiveness, educational modalities, timing and integration topics within the overall curriculum, planned redundancy, and evaluation methods. The second comes from other formal or informal learning experiences within the pre-architectural and architecture study years, including hidden curriculum. The third set of factors includes the study design, questionnaires, and evaluation tools used. We discuss each of these three areas below.

### *5.1 Curriculum characteristics*

Our analysis identified aspects of the curriculum that worked well for our third-year architectural engineering students. We believe that presenting the studio content at Bloom's (1956) taxonomy of higher order thinking skills (understand, apply, analyse, evaluate, create) and the interactive nature of the learning modalities contributed to the improved responses after students participated in the curriculum and after two years. For example, the most improvement was seen in items addressed by interactive sessions, such as the debate and the weekly follow up corrections, where students applied knowledge and practiced skills. Conversely, students' improved mastering of content delivered solely by lecture, such as design principles and guidelines reported in the body of literature, but this knowledge was not sustained at two years. These results and the curriculum evaluation suggest that application-focused learning and case-based interactive or narrative sessions may achieve more lasting impact of students' knowledge, skills, and attitudes, as well as improved student satisfaction with the curriculum. In addition, when we covered topics multiple times using several educational modalities during the curriculum, as in the inevitability of design errors, students' learning was sustained.

On the other hand, several topics let to no change in students' knowledge, skills, and attitudes. For many of these topics, students were already familiar with the concepts that were taught, such as the quality gap between ideal regenerative design philosophy and actual application limitations and it takes more than architects to determine the causes of design errors. Students' prior experiences and baseline knowledge may eliminate the need to cover this material in a curriculum. Alternatively, this lack of change in students' responses might indicate that curricular timing and integration should be improved for these topics. For example, the curriculum did not convince students that regenerative design and circularity in the built environment is a priority at Ulg. This may be due to a lack of clear messages and planned redundancy with the curriculum about our institutional focus on regenerative design. Based on these results, when we presented the curriculum to the next class of third-year architectural engineering student in 2014 and 2015, we decreased the amount of time spent on introductory material, substituted a required reading for a background lecture, and focused more on the interactive, application-based aspects of the curriculum, including the time allotted for students to apply the project requirements in the project design.

### *5.2 Other learning experiences*

Calling to mind the effects of the informal and hidden curricula, our study shows that students' responses to the two items describing secrecy about architectural design errors weakened after one year of architectural practice. Additionally, responses to two items on the value of learning about improving design quality during the study period and working to improve design quality as part of their professional life.

### *5.3 Study design, questionnaire, and evaluation tools*

Limitations in our study design, questionnaire, and evaluation methods also may have blunted the effects of our curriculum on student's learning. A stronger study design would have included a control group of Ulg students or students from similar institutions. However, we thought strongly that all Ulg students should be exposed to this content and thus integrated it into the core curriculum. As this was a novel curriculum and likely to be adapted further, we did not seek to implement it at another institution during this phase of the study. Although the response rate was adequate at each time period, our core analysis focused only on those students who completed the questionnaire at all three administrations. The survey instrument was new and therefore limited by its lack of formal validation and reliability testing. Some attitude items were confusing in that they required the students to respond in a way that reflected both what we taught (i.e., in general architects do not report errors routinely) and what we demonstrated to contrary. Ultimately, our study is limited by reliance on students' self-reporting their comfort with skills and behaviours, rather than our using observational methods to determine their actual performance or measuring design-related outcomes with respect to regenerative design and circularity on the built environment. In addition, students completed the curricular evaluation after the last session, thereby requiring them to recall sessions presented several weeks ago.

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# Bringing a hot topic into the classroom – evolution of a workshop on the food vs fuel conflict

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## Abstract

Sometimes a topic related to your technical course content rises on the agenda in the public debate, and you may want to bring this issue to your students. The conflict over land between biofuels and food was therefore introduced in 2009 in an MSc course, Bioenergy – technology and systems, and has developed since then. This course module is here analyzed under a framework of interdisciplinarity in engineering education. Over time, the teaching of the topic has developed form a very open format to a more focused session, as knowledge has increased. In recent years, activities have been in the form of a half-day workshop where students are given the role of different stakeholders, which debate the conflict of food vs fuel with a biofuel-project in a developing country as a case to focus discussions. Thereby, the unfamiliar topic of food and energy security in low-income countries, is introduced to energy engineering students in a context that they are familiar with. This way of working appears to overcome barriers to interdisciplinary learning, as students see the point of their discipline contributing to addressing an interdisciplinary challenge, as well as the relevance of other disciplines for understanding the challenge at hand. Based on the analysis of interdisciplinarity, learning outcomes for the module have been formulated that can guide further course development.

## 1 Introduction

### *1.1 Background*

Sometimes a topic related to your technical course content rises on the agenda in the public debate, and you may want to bring this issue to your students. That happened when the conflict over land between biofuels and food reached the headlines as fuel and food prices soared in 2008. This topic was therefore introduced in 2009 in an MSc course, Bioenergy – technology and systems, and has developed since then. As knowledge on the topic has developed, and the surrounding circumstances have changed, teaching methods have changed and student learning has differed. It would have been interesting to measure the outcomes of the different teaching methods used over time, but this is not possible due to limited documentation. For the future development in this course, and to provide a wider learning opportunity form this teaching experience, it would still be of interest to reflect on the effect of different teaching methods student learning on this topic. However, before that, it is important to determine what it is that we want to achieve. What learning is it that we want the students to gain from this exercise? After that, the question regarding how to reach the intended learning outcomes can be approached.

Learning objectives have not been specified or analysed in detail while preparing or developing the teaching on food vs fuel. The focus of attention has been on giving students an understanding of the complex issue, on availability of quantitative data that can explain causes and effects, and on relevance of methods and perspectives to the topic. The topic is obviously beyond the scope of a single discipline. The expected learning outcomes and potential methods for achieving this will therefore be analyzed under a framework of interdisciplinarity of engineering education (Richter & Paretti, 2009). An interdisciplinary understanding beyond the narrow frame of the students' own specialization, is one essential aspect of engineering education for sustainable development.

### *1.2 Objectives*

The objective is to report and reflect on experiences of teaching on the conflict over land between biofuels and food in a course on bioenergy for MSc students in energy systems engineering. This is done using concepts on interdisciplinarity in engineering education.

In the first part of the paper, the course module on the food versus fuel conflict, its development and its context is described. In the second part of the paper, the course module is analyzed from the perspective of interdisciplinary learning in engineering education. The analysis leads to the formulation of learning objectives, which can be of use in future development of the learning activities and examination of the module.

## 2 Methods

The method is teacher reflection using course materials, notes, and course evaluations. Concepts on interdisciplinarity in engineering education are used to support and structure the reflection.

## 3 Course module description

The intention with the teaching has been to expose the students to the debate of food vs fuel, and to distinguish facts that can bring some clarity to the problem complex. The complexity of the issue ranged far beyond the technical and environmental expertise of teachers and students. Initially, in 2009-10, the issue was rather hot and all students were well aware of the debate, but at that time very little scientific evidence was available to support teaching. Starting with little knowledge and information about global and regional competition between food and the rapidly growing biofuel market, a full day compulsory workshop was designed, where small groups of students prepared by doing internet searches on different open questions given by the teachers on themes such as land availability for food and fuel, and causes for rising food prices. This was followed by short presentations by the different groups and a large discussion in the class, in order to bring the different perspectives together towards a better understanding of the issue.

At one stage (in 2011), the course as a whole was changed and many more student-active classroom activities and assignments were introduced. For the sake of the course as a whole, it was decided to remove the full-day workshop. As by then there was more scientific information available and the teacher had gained more knowledge of the topic, a lecture was developed on the topic. The topic was examined on the written final exam of the course. However, it was found that the student learning was poor, so the lecturing method was abandoned.

In 2012-15 year, there was a half-day workshop where students were given the role of different stakeholders. Each stakeholder group prepared with questions and literature collected by the teachers, and then groups with one student from each stakeholder group debated the conflict of food vs fuel with a biofuel-project in a developing country as a case to focus discussions. Thereby, the unfamiliar topic of food and energy security in developing countries, was introduced to energy engineering students in a context that they are familiar with. The workshop was followed by a short lecture introducing some additional data and giving teacher perspectives on some of the issues typically raised in group discussions.

The workshop format has proven to be a viable way of teaching this topic, even though the form and content has changed as the course context, teacher knowledge and scientific evidence has developed over time. However, due to an unusually large student group in 2016, a different method was used this year. Two guest lecturers with different perspectives on the topic gave lectures on the issue, which was followed by a class discussion on some of the topics raised. The relevance for this teaching method for the future is yet to be evaluated.

## 4 Interdisciplinarity

### *4.1 Concepts in interdisciplinarity*

Richter and Paretti (2009) identfied two major themes related to interdisciplinarity: (i) relatedness- the students' narrow connection of their discipline to the topic and (ii) perspectives – the students´ wider connection of various disciplines to the interdisciplinary problem. In this case, *relatedness* concerns the link between the students' specialization in energy systems engineering, in particular bioenergy systems, and problems with global land use and the global food system (Figure 1). *Perspectives* concern the two interconnected problems of sustainable land use and food security (Figure 2). Sustainable land use is directly related to land use for biomass production, but there are also many other disciplines that can contribute to this complex issue. Through land use, bioenergy is related to food security. However, there are also a number of other ways in which food and energy are connected, for example power in agriculture; food storage and preparation; and energy for communication and knowledge development on food and agriculture.

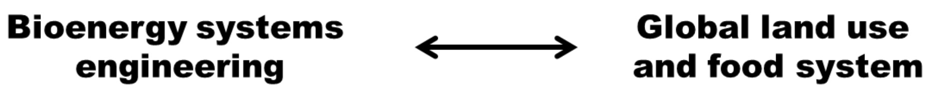


Figure 1. Relatedness between the students' discipline and the interdisciplinary topic

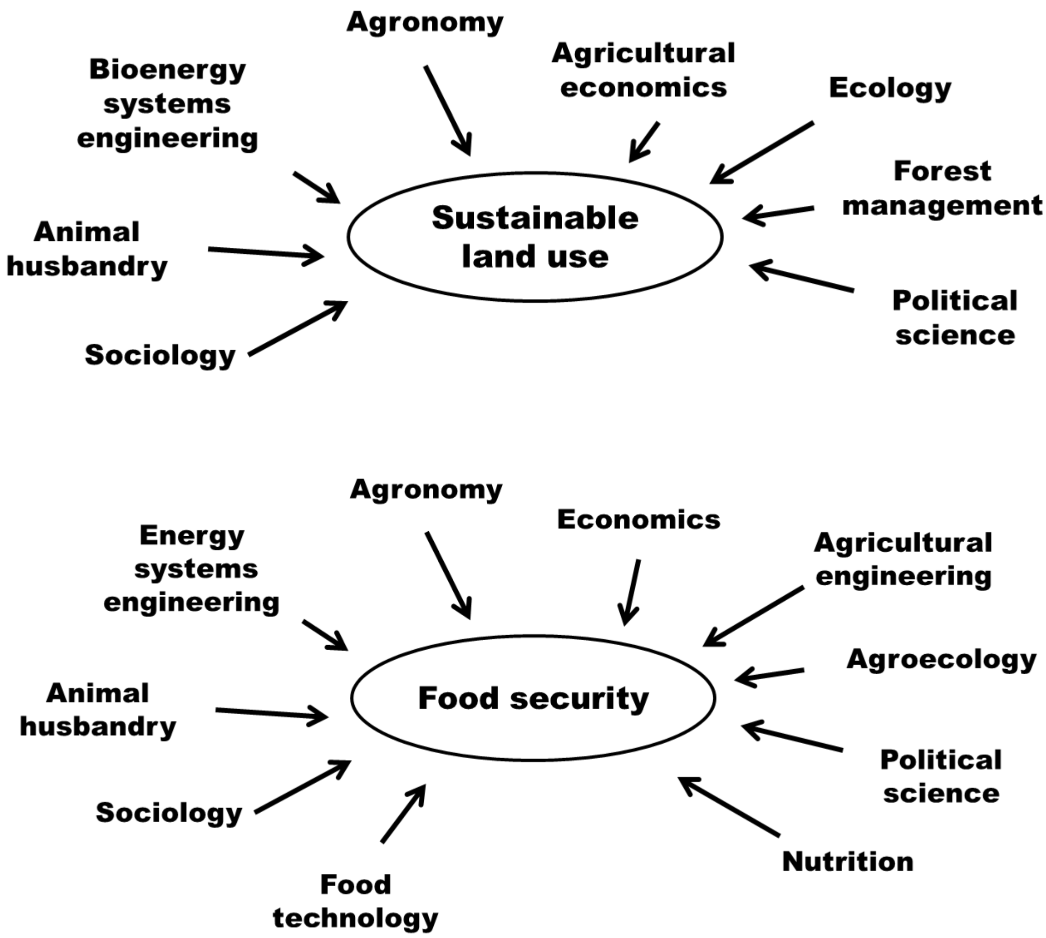


Figure 2. Perspectives on Sustainable land use (above) and Food security (below)

### *4.2 Learning outcomes in interdisciplinarity*

Four general learning outcomes for interdisciplinarity were formulated by Richter and Paretti (2009). The first one is about contributions that new arenas can give to students' own disciplinary expertise. The second is about identifying ways in which their disciplinary expertise can contribute to the solution of interdisciplinary problems. The third is about identifying the value of other disciplines to a particular challenge, and the fourth to synthesize concepts and approaches from various disciplines to develop a solution to a challenge. For this course and this module, the second and third of these learning outcomes are identified as relevant. Two learning outcomes for this course module are formulated related to these:

- Reflect on how implementation of different bioenergy technologies and systems can have direct or indirect impact on food security. (Contribution of their expertise to interdisciplinary problems)
- Explain how bioenergy, among other factors, affects land use and food security, locally and globally. (Contributions from other areas of expertise to a challenge)

The fourth learning outcome (on synthesis of concepts and approaches) is deemed to go beyond the scope of this small course module. The first learning outcome (on contributions from other fields of knowledge to their own expertise) would probably be better addressed in a part of the course that is more technical. For example, there is a biogas project where the students design a biogas system. There, students can gain an understanding of the relevance for design of biogas systems of knowledge from other disciplines about farming systems, especially farm nutrient management.

### *4.3 Methods for interdisciplinary learning*

As for methods to reach learning outcomes about interdisciplinarity, the concept of *disciplinary egocentrism* (the inability to think beyond their own perspective) was identified by Richter and Paretti (2009) as a key barrier to interdisciplinary learning. *Disciplinary egocentrism* can cause *negative relatedness* (”my discipline has nothing to do with this topic”) or *negative perspective* (”other disciplines have nothing to contribute to my work on this topic”).

The food vs fuel conflict provides an immediate link between the students' disciplinary perspective of bioenergy engineering, and issues of global food security. The conflict includes accusations that biofuels cause hunger. This raises an interest in students as to the direct and indirect links between bioenergy and food, but also in other factors that cause food insecurity. This opens a window for learning about other disciplines' *perspectives* on land use and food security. Economic and political causes for food insecurity become of interest to energy engineers. The fuel vs food debate thus seems to provide an excellent opportunity to overcome any *negative relatedness* from students as to the relation between energy systems engineering and food, both global food supply issues and issues regarding food security in the context of poverty in low-income countries.

When changing from a workshop to a lecture in 2011, it was observed that students' learning was less effective. There is no reason to believe that there was any disciplinary egocentrism in that year only. Rather, the explanation should be found in the choice of teaching method in relation to the expected learning outcomes. As the issue is complex, and combines topics that are well known to students with perspectives unknown to them, makes it challenging to use lecture as an effective teaching method. Classroom activities are more likely to be effective if they combine confronting new information from various perspectives with student reflection on the problem complex and the role of his/her energy systems engineering discipline in the context of global land use and food security.

There are many examples of research on interdisciplinarity in engineering education using projects with teams of students from different disciplines. Working with students from other disciplines is then an important part of the students' learning environment. In this case, the student group is rather homogeneous and the module is too small for a project. There is no obvious practical opportunity for collaboration with student groups from other disciplines, so other methods have been used to expose the students to other disciplines. Firstly, literature and lecture content from various sources is a way to expose students to different disciplines. Secondly, in years when role-play have been used, the stakeholder roles have opened up perspectives far beyond the students' own discipline.

## 5 Conclusions

In a course on Bioenergy technology and systems, a module on the food vs fuel conflict was introduced at a time when this was a hot topic in the public debate, while there was little scientific knowledge available on the topic. The course module as changed over the years, due to various circumstances as well as a certain maturity regarding the topic in the scientific community and among teachers. The course module was analysed form the perspective of interdisciplinarity in engineering education. The food vs fuel conflict provides a good case for interdisciplinary learning on relations between energy systems and land use and food security. This is an example of how a hot topic in the public debate, which has some connection to the students' discipline, can facilitate interdisciplinary learning. Through the analysis, learning outcomes have been formulated that can be used in further development of the course teaching of this module. Learning outcomes include understanding the problem at hand from a wider perspective than students' own discipline, as well as reflecting on how their disciplinary knowledge can contribute to solutions of the interdisciplinary problem.

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# Students guiding Societal transitions – examples from Challenge Lab at Chalmers University of Technology, Gothenburg, Sweden

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**Abstract**

Engaging in sustainability transitions of socio-technical systems, where universities need to collaborate with the public- and private sector (together forming the triple helix) is often hindered by various kinds of lock-ins. Actors are in general divided in silo-settings dealing with one issue at a time having narrow perspectives, vested interests and serve goals of sub-systems (or even individual departments) instead of the system as a whole. Furthermore, established socio-technical regimes are subject to path dependencies and incremental realignments. In Sweden, previous attempts to solve this include companies, governmental bodies and researchers acting individually to bring together stakeholders to address the lock-ins. As a complement, a neutral "Challenge Lab" arena built around master students from Chalmers University was established at one of the science parks in Gothenburg. The students may have a unique role to play in the transitions since they are knowledgeable yet unthreatening fostering dialogue between triple helix stakeholders. Interviews with involved actors indicate that students can act as a bonding medium by building trust between stakeholders yet challenging underlying assumptions. Other universities can adopt this model for educating students and engaging in sustainability transitions, even beyond the triple helix.

## 1 Introduction

The United Nations post-2015 development agenda builds upon two key-words: transformation and integration. Transformation in the sense that business as usual is no longer an option, and integration in the sense that the challenges we face demand multilateral actions taking into account all dimensions of sustainability (United Nations, 2015).

United Nations Decade of Education for Sustainable Development (2005-2014) aimed at integrating the principles and practices of sustainable development into all aspects of education and learning, and there is now an increased recognition at the international policy level that education is essential to the advancement of sustainable development. Higher education institutions have stepped up its efforts to support sustainable development having adopted various ESD approaches to reorient learning and teaching practices (UNESCO, 2014). Whole-institution approaches (e.g. Mcmillin & Dyball, 2009; Holmberg et al., 2012) addressing sustainability in campus operations as well as catalysing community change are however concluded in the UNESCO report to be exceptions rather than rules.

Current societal responses towards complex issues and persistent (sustainability) problems have been considered partial and insufficient to bring about the necessary changes such as re- shaping energy-, transportation- and urban systems. To overcome this partiality and insufficiency the concept of socio-technical transitions was introduced, looking at dynamic interactions and co-evolution addressing change at concrete sectoral and/or system levels (Markard, Raven & Truffer, 2012). Efforts to induce/guide/accelerate such transitions are often hindered as current systems are subject to various kinds of lock-ins (Klein-Woolthius, Lankhuizen & Gilsing 2005; Weber & Rohracher, 2012).

The lock-ins can be divided into two broad categories following the logic of the United Nations' emphasis; transformation and integration. The lock-ins hindering transformation occur since existing systems are stabilized by mechanisms creating path dependencies (Unruh, 2000; Walker, 2000) in combination with actors in the system having vested interests using their power to resist change and withstand external pressures (Geels, 2011). The Lock-ins hindering integration is a matter of actors, disciplines and perspectives: our societies tends to be divided in silo-settings handling only one issue at a time, reducing complex issues to simple matters giving rise to externalities elsewhere, cf. Jordan (2011) especially on perspective awareness[1]. Sustainability issues are of a complex nature and the approach to handle them thus needs to be systemic.

A *transformative* approach to tackle complex (unsustainable) issues often contain elements of breaking the thinking free from today's locked-in situation. Action is guided through the gap created by envisioning a desirable future situation on a level of principles or visions (e.g. Holmberg, 1998; Stewart 1993; Senge, Hamilton & Kania, 2015).

An *integrative* approach to tackle complex issues must consist of and increased collaboration across borders, where dialogue and trust building are central approaches to integrate disciplines, actors and perspectives (Jewell-Larsen & Sandow, 1999; Jordan, 2011).

Universities have, by tradition, engaged with persistent problems. University students may have a key-role to play when engaging in such problems (Holmberg, 2014). They can by building trust between stakeholders in the triple helix take the role as change agents. They have the dual capability of being unthreatening yet challenging. Unthreatening, since most stakeholders have been a student, therefore know their situation and can identify with them. In addition, students seldom represent a certain establishment in society with economic, organisational or power incentive stakes in the challenge at hand. Students are challenging as they are knowledgeable and may be somewhat more eager to change than people in professional life, and can therefore question underlying assumptions.

To bring forth the potential that students possess in engaging with societal challenges they need to be trusted as change agents and it can be helpful if they operate from a neutral arena (Holmberg, 2014) providing the space where they can bring together stakeholders and unravel issues. Such spaces are often referred to as Change Labs, Design Labs, Social Innovation Labs or (Sustainability) Transition Labs. These labs are characterised by being social - bringing diverse participants together, experimental - being ongoing and sustained efforts, and systemic - they are trying to come up with solutions addressing root causes of the issues (Hassan, 2014).

A recent survey indicates students lack knowledge in sustainable development and application of the same (Sustainergies, 2015). Another study showed that curriculum development needs to address the interconnectedness of the different aspects of sustainability, by integrating the environmental, economic, social and inter/intragenerational aspect in order to help students understand the complexity and the challenges (Kagawa, 2007).

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[1] Jordan describes in a framework on meaning-making structures of societal change agents' five types of awarenesses: complexity, context, stakeholder, self, and perspective.

On this background; the demand for a deep university engagement in sustainability transitions and the demand for a better capacity among students to handle such issues, the Challenge Lab was initiated at Chalmers University in West Sweden. In the Challenge Lab master students take on complex societal sustainability challenges together with industry, academia and the public sector - related to five regional knowledge clusters; Urban Future, Marine Environment and Maritime Sector, Green Chemistry and Bio-based Products, Sustainable Mobility, and Life Science. The students are considered being change agents in this cluster, backed up by Chalmers' matrix organisation "Areas of Advance" entities: Built Environment, Energy, Information and Communication Technology, Life Science Engineering, Materials Science, Nanoscience and Nanotechnology, Production, and Transport. Currently, the Challenge Lab is built on a preparatory course "Leadership for Sustainability Transitions" and a physical arena for master thesis work located at one of the science parks in the city of Gothenburg.

The purpose of this paper is to present experiences from the students' master theses in the form of cases, complemented with experiences shared in interviews with stakeholders involved in the process. Chapter 2 briefly explains the Challenge Lab concept. Chapter 3 presents some cases from the past three years during which the lab has operated. Chapter 4 discusses the cases in relation to the methodology, asserts, and future development.

## 2 The Challenge Lab concept

In the Challenge Lab students engage as change agents with sustainability challenges in the triple helix. The lab is built around a transformative approach where backcasting is applied and an integrative approach realized through stakeholder dialogues.

### *2.1 Transformation - Backcasting for Sustainability Transitions*

Transitions are characterised by uncertainty, irregularities and long time spans (Rotmans, Kemp & van Asselt, 2001) and due to this the future state cannot be too specifically described. Sustainability transitions are purposive (Smith, Stirling & Berkhout, 2005) and one way to anchor the purpose is through the use of a framework guiding the transition process. A proposed governance model to deal with such processes is transition management (Loorbach, 2007).

One framework to set a transitional purpose, based on criteria for sustainability, is backcasting. Backcasting takes its starting point from a sustainable future situation. The future situation is not described in detail but rather on a level of principles, which then act as a frame for many possible futures (Holmberg & Robèrt, 2000). Backcasting is particularly useful when the problem to be studied is complex; there is a need for major change; dominant trends are part of the problem; the problem to a great extent is a matter of externalities; and when the scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice (Dreborg, 1996).

Challenge Lab follows a backcasting approach (Holmberg, 1998) applied on a regional scale, where the students start with clarifying their values (Holmberg, 2014) and defining sustainability criteria (step 1). The students then analyze today's socio-technical systems in relation to the criteria (step 2) through the lens of ongoing local-regional processes. The analysis is done by applying tools such as systems dynamics (Forrester, 1994) and the multi-level perspective (Geels, 2002). Within the dynamics of the gap between what should be (step 1) and what is (step 2) the students formulate research questions and identify leverage points suitable for intervention (Meadows, 1997). The questions and leverage points become the starting point for dialogues (Isaacs, 1993; Sandow & Allen, 2005) where stakeholders relevant for the analyzed processes are invited. From these dialogues the students iterate on their problem formulation, team up and let their research questions be the input to a design process (Lawson, 1997) (solution envisioning, step 3). The strategies for realizing them (step 4) are supported by diffusion theories (Robinson, 2013) and scenario planning (Schwartz, 1992).

This process means that the students do not start their 20 week thesis from a pre-defined research question ‘nor an assigned supervisor. Instead, they take a step back and spend the first four weeks by identifying their own research question emerging from a critical sustainability challenge identified by going through the first two steps of backcasting.

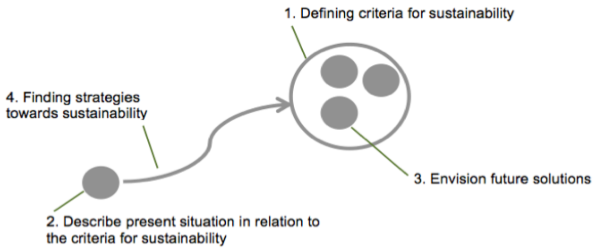


Figure 1: The four steps in the Backcasting framework (Holmberg, 1998)

### *2.2 Integration – dialogues facilitated by students in a neutral arena*

Many projects and methods aspire to gather actors to share perceptions, create trust and resolve conflicts. In the neutral arena, multiple actors can act simultaneously to *integrate* perspectives. These settings have the potential of dislodging silo-thinking by broadening the scope of how challenges and problems are framed and defined (Hickey & Mohan, 2004).

In the Challenge Lab the neutral arena is realized by the placement of the lab in a science park, in the metaphorical “middle of the two triangles”. One triangle representing the triple helix (academia, industry and society) and the other representing the knowledge triangle (research, education and innovation). Here, it is possible for the students to connect actors from industry, researchers, and also the authorities and departments within the city and region (figure 2).

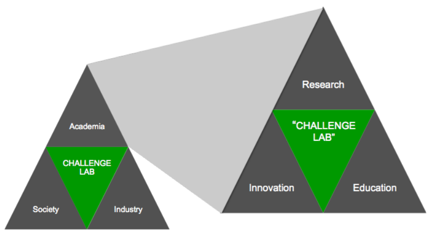


Figure 2: The Challenge Lab is uniting research, innovation and education within the university and in a societal context, the lab is then uniting academia, society and industry.

## 3 Examples of master theses

The overall structure for the case examples in this chapter is following the main lock-in addressed relating to either *transformation* or *integration* followed by a description of each specific case.

### *3.1 Transformative backcasting approaches*

Below three cases are presented where the use of sustainability principles was central in the thesis.

#### 3.1.1 Case A: The Regional climate strategy in Region Västra Götaland, Sweden 2015

"Two of the students in the lab were doing their Challenge Lab master thesis connected to a project where the Region Västra Götaland were developing a climate strategy towards a fossil independent region 2030. The project group consisted of civil servants, with support from two researchers, who were identifying suitable themes upon which backcasting multi-stakeholder workshops were to be conducted during the fall 2015. After some meetings with representatives of the project group, the students identified two things; first that the time frame seemed narrow to achieve the desired transformation, second that there might be co-benefits if more sustainability challenges than the climate issue got equal attention in the strategy, something the project group also had acknowledged while setting up the workshop themes.

In a dialogue setting at the Region office, the time frame was discussed in relation to the long-term purpose of the strategy. **During this dialogue it was agreed that it was better to free up space by aiming for the 2050 target of being fossil free.** The fossil independency goal of 2030 could be seen as an interim target to keep the urgency to act. With this longer time frame it will be easier to free the mind from today's systems and think about transformative solutions. The workshop themes could also be broadened up and address wider socio-technical systems in need of transformation by integrating more sustainability aspects than fossil carbon emissions." (Jörgen Larsson - Group member of the Region Västra Götaland project group, personal communication, August 4, 2015)

#### 3.1.2 Case B: Challenging funding of sustainability effort in industry 2015

The tools used in the course Leadership for Sustainability Transitions were applied in a master thesis at Chalmers University of Technology where the students were acting as change agents in an industrial setting within a large chemical agent producer. They were introducing new thinking by applying a broader perspective on sustainability and challenging the current mental models within the company. The students introduced a new way of looking at green bond investments within the company. This is a process that is coloured by internal corporate politics, but according to the manager of the sustainable development group, the students could do this, due to the unique character as unthreatening and not part of company internal politics.

During this intervention it was experienced the students could access stakeholders in the company and pose challenging questions to the finance department that would not have been possible for the sustainability group, due to the ability of the students to be blue-eyed and "naïve" "in another way as the other can. They are not seen per definition as a threat". (Claes Hallberg - Manager Sustainable Development Group AkzoNobel, personal communication, June 3, 2015)

#### 3.1.3 Case C: Sustainability principles at Chalmers Restaurant and Conference company 2014

The course initiated a cross-disciplinary project involving researchers, personnel, and students. The project was started during the fall of 2014 and was developing into an initiative in the university Restaurant and Conference company. The students initiating this were using tools from the course Leadership for Sustainability Transitions.

The student intervention was seen as positive and created curiosity and interest in what the restaurant believes in and stand for. Through this work the restaurant's sustainability efforts was on the table for real and students that have insights now think their work is done well and that the restaurant is doing the right thing (Magnus Danielsson - vice president Chalmers Conference and Restaurants, personal communication, June 10, 2015).

## *3.2 Integrating actors, disciplines and perspectives in the neutral arena*

Below four cases are presented where dialogue were a central part of the thesis.

### 3.2.1 Case D: Dialogue on electromobility scenarios for Gothenburg city 2016

Two students identified during the initial stakeholder dialogues at the lab that there currently was no actor in the region considering what a large-scale diffusion of electromobility would mean for Gothenburg City, even though such diffusion would have benefits regarding low-carbon futures and have a potential to disrupt existing city planning processes. The students connected with the Gothenburg traffic office and invited 15 stakeholders from academia, public and private sector, in a dialogue to discuss potential implications such a large-scale diffusion would have on the city and what strategies would be needed to guide such development in a sustainable direction.

After this dialogue the Traffic Office considered the dialogue an important component in their current strategy and have therefore invited the students to follow up the dialogue. The other actors involved also wished to be part of further discussions to include the issue of electromobility in their future work (Malin Anderson, head of department development and international affairs Traffic Office Gothenburg, personal communication 13th may 2016)

### 3.2.2 Case E: Dialogue to introduce solar energy for a sustainable campus 2015

This project, within the Challenge Lab 2015, was exploring a research question in, where one Challenge Lab student was initiating dialogues within a number of diverse stakeholders at the university campus. The response from one stakeholder showed that the Challenge Lab project was creating a change in the stakeholder group and also added stakeholders to the dialogue. These stakeholders were initially unaware of each other on the onset of the dialogue sessions. The project was reinforcing already established stakeholder relations and also induced and created new ones.

Through the dialogue the understanding of the actors' respective work has become better. The stakeholders reached the essence of what is important to focus on for all of them. The process was believed to take a leap forward when the students began to unravel and untie the issues (Magnus Wennergren - Environmental Coordinator Chalmers University of Technology, personal communication, June 1, 2015).

### 3.2.3 Case F: Connecting actors within Chalmers Areas of Advance and beyond 2015

Two students doing their thesis started questioning the storm water strategies currently discussed in the University and the city and looked at novel solutions in the concept of bioretention planters allowing for cost-efficient storm water handling. Through interactions with stakeholders the students opened up a new perspective and made two research groups look into a common new area. "*Our main focus on storm water handling is through filters, but* ***the students gave us new perspectives*** *on the rain garden concept. I also think that the other research group opened their eyes for this concept.* ***We should push more for this in future research applications***" (emphasis added, Ann-Margret Strömvall - Associate Professor Civil and Environmental Engineering Water Environment Technology Chalmers University of Technology, August 3, 2015).

During the final presentation of this project representatives from a municipal park authority and a municipal wastewater treatment company were present. The project involved stakeholders from the city authorities, and concluded that these had to increase the collaboration to realise the proposed concept. The two representatives got to meet since the Challenge Lab change agents connected them.

The concept was novel and interesting enough for the Chalmers University of Technology campus development group to finance a pre-study for the implementation of this concept.

#### 3.2.4 Case G: Authorities within the municipality - Creating trust and courage to act 2014

A civil servant from the Public Transport Authority in the Region Västra Götaland was invited for a stakeholder dialogue with the students of the Challenge Lab 2014 cohort. The civil servant was alone with the students and the Challenge Lab coordinator was recording the dialogue. The students had all been equipped with dialogue tools from previous theory modules in the initiation of the master thesis. The dialogue was including subjects ranging from technology and politics, and was heavily leaned to discussion regarding the democratic process. After the interview, the civil servant spontaneously stated that he said things in the dialogue that he would not do at work. "**In the dialogue I was stating things that I would not normally say as a civil servant**" (Civil servant - Public Transport Secretariat Region Västra Götaland, personal communication, March 7, 2014).

## 4. Discussion and conclusion

We have presented a setting to engage in lock-ins, based on students applying backcasting in a neutral arena. The aim was to through a Challenge Lab engage in sustainability transitions and educate students. Some results and experiences from the first three years of the Lab were described.

The three cases presented in 3.1 exemplify the ***transformative capacity*** of the Challenge Lab. Here, the students could widen the perspectives in how issues were approached thus challenge current practices. This "interventionist approach" aimed towards catalysing sustainability transitions in socio-technical systems and thus reduced the risk having the regime itself shaping their innovative activities through endogenous renewal; leading to incremental and path following transformation processes (Smith et al., 2005).

The four cases presented in 3.2 exemplify the ***integrative capacity*** of the Challenge Lab. Here, the students gathered stakeholders from academia, public and private sector in dialogues to understand their perspectives and situations. In connecting separate organisation and research fields, the students by proposing questions, issues and solutions has served as connectors of perspectives and thus as integrated the thinking between actors. "By succeeding in initiating a transformation of certain stakeholders' perspectives, it might become possible to accomplish other goals, such as realizing a vision" (Jordan, 2011 p. 81).

The methodology used here, where students operate in a neutral arena following a backcasting process makes the Challenge Lab complementary to the general concept of "social labs" researched. Social labs often start in (societal) needs that seek solutions. Their process can be described as *demand-driven innovation*. This is an important expansion and complement to the general *idea-driven innovation* process at universities.

We argue that, in order to be even more relevant for sustainability transitions, it is also important to take a *sustainability-driven innovation* approach - staying in the question and then searching for needs and demands within this question from a sustainability perspective. The approach at the Challenge Lab, has been based on taking a step back and stay in the challenge and identify the gap between a future sustainable state and today's situation. Once this gap is identified, a design process can start which identifies the needs and demands within this sustainability challenge.

In conclusion, we have seen so far the capacities of students to deliver transformative and integrative capabilities to support transitional processes towards sustainability. We have experiences that there are benefits of approaching society through the students - due to their unique characteristic of being unthreatening yet challenging. Therefore, to expand the capacity of the university to both conduct education and be relevant for society, providing the space for students to act as change agents to engage in real-world issues has so far delivered some promising results.

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## Appendix A: Full version of interview transcripts from Case B, Case C, and Case E (summarized version in article)

*Each statement and quote presented in this paper have been confirmed by the interviewee concerned*

**Interview with** Claes Hallberg, 2015 - Manager Sustainable Development Group AkzoNobel

*"If I or anyone else in our Sustainability group was to ask our finance department some questions, we could not just do that, since it is politically sensitive and you don't need to have that political sensitiveness when you come from the outside, just like* ***"I am just a young student I can ask anything".*** *Then it does not really matter in the same way.* ***The students are change agents in the sense that they do not need to be involved in the internal politics in the company. They do not need to take into consideration the internal politics in our organization, in the same way any employee inside our organization has to take. It is a fact.*** *They can be "blue-eyed" and naive or pretend to be blue eyed and naive in another way as the other can.* ***They are not seen per definition as a threat.*** *If I were to ask the questions a student is asking, then someone would ask "why are you asking that??" "are you after my job?" Ok, they are not saying it explicitly, but they are thinking it inside of their heads. But they are not thinking that of a student. Many are thinking of the student regardless of their subject as a "fresh wind" coming into the organization. The students who are coming in to us in the later stages of their studies are knowing things that we do not know, since we have been behind a desk for a number of years.* ***People in the organization are aware of that and want to have the students' opinion*** *and see what the students want or look into what areas the students are focusing on. Then there is the backside where people do not think they have time to work with the students. Maybe they think, this is not giving me anything in return. But generally there is a positive stance to having the student interviewing."* (Claes Hallberg - Manager Sustainable Development Group AkzoNobel, personal communication, June 3, 2015)

Interview with Magnus Danielsson, 2015 - vice president Chalmers Conference and Restaurants

***"I would like to say that the student involvement was only positive. It created a curiosity and interest in what we really believe in and stand for, but also the will to be of influence.*** *The most positive thing that occurred was that we have had a question in our guest survey regarding what our members (the students) think about our sustainability efforts. For many years the answer has been "No opinion" or that it is simply flat bad. Now, in this work, the question was "on the table" for real and the ones that have insights think our work is done well and that we are doing the right thing. The question is so complex mainly because the research is not in line with what the average person on the street thinks when they go to shop groceries. Everything is so much more complex. Now we have started a working group that - in collaboration with us and the university (Chalmers University of Technology) - will create a proposal for an internal eco-label that goes along with what research is telling us - that have peer-reviewed research behind it. Not just a "Green bird"-label. Many times it is emotions that tells you it is better with ecological carrots from Africa to your beef. We have seen an increased interest in vegetarian food.* ***The students' influence has given us contacts with other parts of the university that we did not work with before.*** *The most important is that it is not only talk, but also action. The work is also beyond doing a good master thesis or doing a good job at work, but to raise awareness to leave a better world to the ones coming after us. The question I ask myself is if it is worth eating a beef with mashed potatoes for lunch - and at the same time knowing this has equivalent emissions of 30* *vegetarian lunches in terms of CO2?"* (Magnus Danielsson - vice president Chalmers Conference and Restaurants, personal communication, June 10, 2015).

Interview with Magnus Wennergren, 2015 - Environmental Coordinator Chalmers University of Technology

*"**Through the dialogue step and the interviews conducted, I have experienced the understanding of our respective work within energy, in each organization has become much better.** Since we usually are "sitting on" our own issues in our respective chambers in our respective organizations, the work tend to sprawl too much. [Furthermore] **the different organizations own agendas tend to be prioritized when it comes to the strategic and operational work to be coordinated** between, for example Chalmers University of Technology, Chalmers Fastigheter (the University real estate company) and Akademiska Hus (the state-owned university real estate company).*

***By letting the students start to working on the issues on energy efficiency on campus, we reached the essence of what is important to focus on for us all as stakeholders.** Since I am a coordinator and has had dialogues with various stakeholders before, I felt that **the process took a leap forward when the students began to unravel and "untie" the issues.** The dialogues, and the interviews were crucial to **give the work the push forward, that would otherwise have taken another 6 months to complete.** Through the dialogue with the students, I got even more input into my work and strengthened my questions from a larger width than before."* (Magnus Wennergren - Environmental Coordinator Chalmers University of Technology, personal communication, June 1, 2015)

# Stakeholders versus education for sustainable development within the industrial engineer curriculum

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## Abstract

Engineering Students will acquire the skills to learn, analyse, synthesize and creatively apply engineering principles to new problems, and should take into account the human dimensions of technology, cultural diversity and globalization. The new scenario will require a way of teaching and assessing according to the learning styles of today's students and the involvement the stakeholders, industry, public authorities and professional Institutions.

This research was conducted for the curriculum in industrial engineering within the framework defined by the United Nations in Agenda 2030 for sustainable development and the criteria of the 2015 University Strategy for Spanish universities. The main objective of this research is to validate a methodology to address education for sustainable development within the industrial engineer curriculum that will define the content, skills and learning methods in a process of continuous improvement and compatible with the national curriculum regulations for the Bachelor and Master of the IQS School of Engineering

In order to validate the model the stakeholders, industry, public authorities and academia will be involved developing the Delphi Method. The public authorities and industry stakeholders will be asked in terms of content and skills, the academy will be asked to validate the teaching methods and the implementation. The results will determine the main skills to develop their work, to what extent have these skills the new graduates, and the areas to be considered now to move towards a sustainable development.

In this presentation the framework on which we can developed the model validation will be defined. We must show the evolution towards more and better acquisition of skills for sustainable development after we have incorporated the outcomes for sustainable development into the training activities. The first step is to compare the knowledge in sustainable development that new under graduated students had in relation to final year student's knowledge. We analysed concept and mental maps made in first and fifth grade evaluating the relationships between concepts and categories. In a second study, we have analysed the incorporation of sustainable development concepts in the final work (last course of the studies), contrasting the results with those obtained from the analysis of final works from other universities. As well we analyse a regional survey to employers in order to set a reference model.

This previous research will set the survey content and the expert panel of stakeholders, industry, public authorities and academia.

# 1 Introduction

## *1.1 Learning Styles*

Students will acquire the skills to learn, analyse, synthesize and creatively apply engineering principles to new problems, and should take into account the human dimensions of technology, cultural diversity and globalization. The new scenario will require a way of teaching and assessing according to the learning styles of today's students.

This research was conducted for the curriculum in industrial engineering within the framework that defines the implementation of the Bologna Declaration on Higher Education in Spain. It was developed for the Undergraduate and Master's degree program in Industrial Engineering at IQS School of engineering, federal member of the University Ramon Llull (URL).

Since 2005 a survey to find out more about the different learning styles of our students has been conducted (Felder R, M, 2002). In the surveys of the 2008-2009 and 2009-2010 were 230 answers, 87% said that they prefer to acquire new knowledge in a concrete and practical way, only 5.7 % to acquire knowledge in a conceptual way, oriented towards theories and meanings, and the rest 7.3 % were undecided. Besides, 75% prefer visual representations of presented material, 6.5 % prefer written and spoken explanations. When asked about their attitude to the learning process: 77% had an active attitude and 16.1% were reflective learners. Up to 80% are sequential learners, and global learners, holistic and systematic thinkers 16%.

From the results can be summarize that the majority of ours students are sensitive, visual, active and sequential leaners. Most engineering instruction in the past few decades has been heavily biased toward intuitive, verbal, reflective and sequential learners but relatively few engineering students fall into all these categories.

De Graff (2006) reduces the Felder's categories in four categories: doers, thinkers, deciders and dreamers. Considering these four categories most of the students are doers, some thinkers, few are deciders and only 5 of the students out of the 230 are dreamers.

These different learning styles need to be taken into account in the design of education programs. (Kastenhofer, K., et al. 2010). Considering that the research students will be more comfortable with concrete and active experiences, the need to start with concrete and active learning activities seems more convenient. A recent analysis of sustainable competences in engineering education shows that most competences are: critical thinking, systemic thinking, inter-trans-disciplinary and values and ethics (Segalàs, J, 2009). All of them need a global and holistic view. Students must progress on global and reflexive attitudes even they started as sequential.

## *1.2 Industrial engineering in Spain.*

In Spain, most of the schools of engineering started the under graduate Bologna degree program in 2010-11 and the Master in 2014-15. The analysis of the Spanish degree and Master, its regulations and outcomes, and analysis of the learning styles of our students, permit develop a proposal for embedding sustainability in the industrial Engineering curriculum according to the learning styles of actual students as individuals.

According to regulations, the first year of the undergraduate industrial degree is formed by basic subjects. Chemistry and economy are basic subjects and very relevant on sustainable development. The learning activities in the first year would aim to understand the natural and social system present in our society, how humans have modified those systems and to understand the role of technology based on models of successful experiences. It is considered a priority for first contact, right at the start of training, to promote a particular way of thinking that incorporates a new aspect to the design of production process. (Kamp, L 2006)

As a first step towards incorporating sustainability concepts into all disciplines to be taught in subjects from the second to the fourth year, the proposal is to introduce a guest speaker of a particular discipline who can provide expertise in all aspects of sustainable development specific to their discipline

The professional outcomes of the Spanish degree CP1- Environmental Technology and CP2 - Professional ethics related to and will be achieved through two subjects of the old degree but with new styles.

The Practicum and final project will facilitate the incorporation of the competence for sustainability and assess the integration in the project development. However it is not until later in the senior or graduate years that students become introduced to more complex, ambiguous problems through case studios, research, and design experience. Most under graduate students acquired a level far short of "contextual knowing" one of the relevant skills for sustainable development. (Huntzinger D.N, et al 2007). It is in the master final projects that students will demonstrate whether they have acquired competence for solving complex problems, taking into account issues of sustainable development.

## 2 Objective

This presentations is part of a thesis research which main objective is to validate a methodology to address education for sustainable development within the industrial engineer curriculum that will define the content, skills and learning methods in a process of continuous improvement and compatible with the national curriculum regulations for the Bachelor and Master of the IQS School of Engineering

In order to validate the model the stakeholders, industry, public authorities and academia will be involved developing the Delphi Method during May and June 2016. The public authorities and industry stakeholders will be asked in terms of content and skills, the academy will be asked to validate the teaching methods and their implementation.

In this presentation will be defined the framework on which we can develop the model validation. We must show the evolution towards more and better acquisition of skills for sustainable development. The first step is to compare the knowledge in sustainable development that new under graded students had in relation to final year student's knowledge. We analysed concept and mental maps made in first and fifth grade evaluating the relationships between concepts and categories. In a second study, we have analysed the incorporation of sustainable development concepts in the final work, contrasting the results with those obtained from the analysis of final works from other universities. As well we analyse a regional survey to employers in order to set a reference model.

This previous research will set the survey content and the expert panel of stakeholders, industry, public authorities and academia.

## 3 Sustainable development knowledge: Undergraduate versus graduate students

The concept maps can be considered excellent for assessing student knowledge in a certain subject. The concept maps stimulate them to articulate and demonstrate the current state of knowledge. Novak and Goowin (1984) claimed that concept maps is a creative activity in which an effort to clarify the meanings of concepts in the area of knowledge should be made. The students were asked to write and connect all the concepts they associated to sustainable development. According to Segalàs (2009) ten semantic categories are used to analyse the concept map: Environmental aspects, Resources scarcity, Social Impact, Cultural & Values aspects, Future generations, Unbalances, Technology, Economical aspects, Education aspects, and Actors and Stakeholders. The words that were written on the maps were assigned into one of those ten categories. The first year industrial technology degree students and the 5th year of industrial engineering students were asked to associate about 15 concepts related to the sustainable development. The 68 maps of the first year students and the 31 maps of the 5th year students were analysed during the 2011-2012.

The map analysis provides information on what a student course group believes what sustainability is more related. Category relevance (CR) is calculated as the average of the percentages of concepts for each category of all students in a course.

Table 1: The category relevance (CR) expressed in the 68 concepts maps of the first year students

| Categories | Description | Number of concepts NC | % of concepts in one category | Number of students NS | % of students | **CR** |
|---|---|---|---|---|---|---|
| 1 | Environmental aspects | 252 | 24,39 | 61 | 89,71 | **28,52** |
| 2 | Resources scarcity | 94 | 9,10 | 44 | 64,71 | **7,67** |
| 3 | Social Impact | 87 | 8,42 | 31 | 45,59 | **5** |
| 4 | Cultural & Values aspects | 14 | 1,36 | 8 | 11,76 | **0,21** |
| 5 | Future generations | 15 | 1,45 | 11 | 16,18 | **0,31** |
| 6 | Unbalances | 36 | 3,48 | 24 | 35,29 | **1,60** |
| 7 | Technology | 356 | 34,46 | 66 | 97,06 | **43,60** |
| 8 | Economical aspects | 107 | 10,36 | 51 | 75 | **10,13** |
| 9 | Education aspects | 43 | 4,16 | 25 | 36,76 | **1,99** |
| 10 | Actors and Stakeholders | 29 | 2,81 | 18 | 26,4 | **0,97** |

Table 2: The category relevance (CR) expressed in the 31 concepts maps of the 5th year students

| Categories | Description | Number of concepts NC | % of concepts in one category | Number of students NS | % of students | **CR** |
|---|---|---|---|---|---|---|
| 1 | Environmental aspects | 78 | 7,96 | 25 | 80,65 | **18,11** |
| 2 | Resources scarcity | 35 | 3,57 | 23 | 74,19 | **7,48** |
| 3 | Social Impact | 13 | 1,33 | 12 | 38,71 | **1,45** |
| 4 | Cultural & Values aspects | 20 | 2,04 | 12 | 38,71 | **2,23** |
| 5 | Future generations | 20 | 2,04 | 16 | 51,61 | **2,97** |
| 6 | Unbalances | 17 | 1,73 | 15 | 48,39 | **2,37** |
| 7 | Technology | 167 | 16,94 | 30 | 96,77 | **46,26** |
| 8 | Economical aspects | 57 | 5,82 | 27 | 87,10 | **14,30** |
| 9 | Education aspects | 24 | 2,45 | 13 | 41,94 | **2,90** |
| 10 | Actors and Stakeholders | 16 | 1,63 | 13 | 41,94 | **1,93** |

A first analysis tells us that during the process of learning, the category relevance (CR) related with the technology and economy increase and decrease the contents related to the environment. The Social impact, The Cultural & Values aspects, Future generations and Unbalance and those related to Actors and stakeholders with low presence rises slightly.

The social categories, Social impact, The Cultural & Values aspects, Future generations and Unbalance concepts get a low percentage of number of different concepts but a 38 up to 41% of the students assigned at least one concept in each category.

## 4 Sustainable development in the engineering final work (PFC)

In the second study, we have analysed the incorporation of sustainable development concepts in the PFC, contrasting the results with those obtained from the analysis of final works from other universities. Up to 2012 a hundred and seventeen Final Projects (PFC) have been defended. Only 54 projects have considerate concepts related to Sustainable development. The Technology and the Environmental aspects are the categories with higher number of concepts assigned. We can observe three categories without concepts. The students don't consider the Cultural &Values aspects, Unbalances and Education aspects in theirs PFC. The social impact category only get the 4% and the Economical aspects the 7% of the concepts assigned.

Table 3: Sustainable development concepts in PFC.

| **Categories** | Concepts | % |
|---|---|---|
| Environmental aspects | 44 | 29 |
| Resources scarcity | 16 | 11 |
| Social Impact | 6 | 4 |
| Cultural &Values aspects | 0 | 0 |
| Future generations | 3 | 2 |
| Unbalances | 0 | 0 |
| Technology | 65 | 43 |
| Economical aspects | 10 | 7 |
| Education aspects | 0 | 0 |
| Actors and Stakeholders | 23 | 15 |

If we ~~analyses~~ the PFC defended in the Industrial engineering program at the Universitat Politecnica de Catalunya (UPC) we will observe that from 2005 to 2012 only 21 of the 1845 defended have the key word sustainability.

## 5 Institutional surveys

Since 2001 there are studies of employment of the Catalan universities, coordinated by Agència per la Qualitat del Sistema Universitari de Catalunya (AQU). The social councils of the Catalan universities are interested to obtain data and references on the suitability of the educative objectives and the preparation of graduated people respect to the professional market demands and are carried out at three-year intervals on population graduated three years earlier. In the fourth Edition were involved, for the first time, all the private universities and a total of 22 centres attached. If we consider the results of the last three studies, globally, the training level received in almost all of the transversal competences is valued above the approved. The Table 5 provides data about the shortage of training, i.e. the difference between the average of each competence which is considered necessary to develop the current work and the average of the level of training received at the University about this competence. (AQU CATALUNYA, 2014)

The Responsibility at work has the highest value, and are considerate important the Learning skills ability to adapt to new situation and the team work. The highest difference between the necessary and the received is in Problem solving and practical training.

Table 5: Comparison of recent graduates' competences averages of importance and the level received (2014)

| Typology | Competences | Desirable | Received | Difference |
|---|---|---|---|---|
| **Disciplinary contents** | Theorical training | 7,2 | 7,2 | 0,0 |
| | Practical training | 7,7 | 6,1 | -1,6 |
| **Cognitive outcomes** | Problem solving | 8,2 | 6,5 | -1,7 |
| | Mathematical skills | 7,0 | 6,9 | -0,1 |
| | Decision making | 7,6 | 6,2 | -1,4 |
| | Capacity to generate new ideas. | 8,0 | 6,6 | -1,5 |
| **Personal Management outcomes** | Learning skills ability to adapt to new situation | 8,3 | 6,7 | -1,4 |
| | Autonomous work | 7,7 | 6,7 | -1,1 |
| **Instrumentals outcomes** | Communicate skills | 7,9 | 6,7 | -1,2 |
| | Languages | 7,6 | 6,7 | -1,1 |
| | IT skills | 8,2 | 7,9 | -0,4 |
| **Interpersonal outcomes** | Team work | 8,3 | 7,5 | -0.9 |
| | Leadership skills | 6,6 | 5,8 | -0.9 |
| | Negotiation skills | 6,4 | 5,7 | -0.9 |
| **Attitude i ethical professional.** | Responsibility at work | 8,9 | 7,6 | -1,4 |

## 6 The survey content and the expert panel of stakeholders, industry, public authorities and academia.

In order to validate the model the stakeholders, industry, public authorities and academia will be involved developing the Delphi Method during May and June 2016. The public authorities and industry stakeholders will be asked in terms of content and skills, the academy will be asked to validate the teaching methods and their implementation. This previous research will set the survey content and the expert panel of stakeholders, industry, public authorities and academia. The experts' panel questions will be set in three groups. In the first group of questions they will be asked to assign the order of relevance to the categories Environmental aspects, Resources scarcity, Social Impact, Cultural & Values aspects, Future generations, Unbalances, Technology, Economical aspects, Educational aspects, Actors and stakeholders to advance towards sustainable development .

In the second part of the survey the experts decide the relevance of the following competencies, Table 6, to prepare graduated people to the demands of the professional market. And the level the graduate achieve on these competencies. The competences were organized in six typologies, the same used in Table 5, in order to be able to compare the results of our future research with the AQU, 2014 results. The competences are related to the sustainable development need.

The third question group is related to the curriculum and how must be included the sustainability criteria within the engineering curriculum (degree + master). There are defined three options: 1) embedded the sustainable concepts in the subjects, 2) show recent real cases, 3) develop projects.

The panel of experts will be composed by public authorities of the administration and professional institutions, senior Engineers, IQS engineers and multidisciplinary experts.

Table 6: Competences

| | |
|---|---|
| **Disciplinary contents** | 1. Have acquired advanced knowledge that allow to understand the challenges of sustainable development related to the practice of engineering.<br>2. Consider knowledge of different engineering disciplines to achieve objectives of sustainable development in the practice of engineering. |
| **Cognitive outcomes** | 3. Use an approximation holistic and systematic to explore solutions to complex problems.<br>4. Develop and structure ideas and proposals in a creative way and with critical reasoning<br>5. Know the strategies to minimize the environmental and social impacts of a project<br>6 Develop technical projects considering the impacts, risks and social and the environment |
| **Personal Management outcomes** | 7. Manage the new situations. |
| **Instrumentals outcomes** | 8. Communicate ideas and efficient proposals related to sustainable development. |
| **Interpersonal outcomes** | 9. Working with others as members of a multidisciplinary team with opinions that do not have to coincide with the own.<br>10. Working with others in a multilingual environment and different cultural backgrounds.<br>11. Facilitate the participation of all parties involved in the decision-making process during the development of my projects |
| **Attitude and ethical professional.** | 12. Demonstrate an understanding of the importance of professional ethics and the consideration of all parties involved.<br>13. Identify the potential challenges, risks and the consequences of how the engineering practice impacts on society and the environment<br>14. Guide of ethical and responsible professional activity in the framework of organisations, administrations, companies or teams |

## 7 Conclusions

The analysis of the concepts maps shows that during the process of learning, our students get a more complex vision so the concepts related with the technology and economy increase and decrease the contents related to the environment. The Social impact, The Cultural & Values aspects, Future generations and Unbalance and those related to Actors and stakeholders with low presence rises slightly.

This complex vision is not reflected in the Final Project (PFC) where the Technology and the Environmental aspects are the categories with higher number of concepts assigned and the students don't consider the Cultural &Values aspects, Unbalances and Education aspects in theirs PFC.

According to the national survey the Responsibility at work has the highest value, and are considered important the Learning skills ability to adapt to new situation and the team work. The highest difference between the necessary and the received is in Problem solving and practical training. Once more the practical aspects, the professional practice must be improve. The competences are relevant to a sustainable development of the world.

These previous researches will set the structure of the survey to the stakeholder, the public authorities and the professional institutions, and the experts multidisciplinary will be develop on June 2016. The results of these previous researches will be used as model reference when analyse the survey values.

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# What happened to the Industrial Ecologist alumni? A survey of occupations, activities, competences and skills

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**Abstract**

A number of think tanks in Europe states that there is a need for a new type of engineer that is able to assist industry to reroute linear economic and material flows to circular. These engineers should be systems thinkers for sustainable development, communicative and also be able to take on the leadership for holistic problem solving. In quite a few universities around Europe there are educations in Industrial Ecology that meet these demands. Based on a survey coordinated from Chalmers University of technology of what former Industrial Ecology students work with after they finished their education was conducted during the spring 2015. The survey went out to around 500 Industrial Ecology alumni in the world but mainly in Europe.

The aim of this contribution to the EESD16 is to present the results of the survey and further to contribute with a discussion on how different skills and competences are developed during the Industrial Ecology education which could inspire engineering education in general for future curriculum developments. The aim is also to reflect on the reasons why industry and alumni from Industrial ecology do not find each other.

The preliminary analysis of the survey shows that a large group alumni end up in various research activities rather than working in industry, despite the need in industry and educators hope. The results also indicate that the Industrial Ecology alumni is mainly a LCA practitioner, despite the number of .different Industrial Ecology tools in the toolbox. The results also indicate that a relatively large group is not completely satisfied with their work and the limited amount of systems thinking in their everyday work life.

## 1 Introduction

European Think tanks discuss the future of industry and stress the need of skills of the workforce for a New economy. In the New economy manufacturing processes are resource efficient and circular rather than linear. This calls for a new type of specialists that have broad generalist abilities based in systems thinking for sustainable development and the ability to link disciplines into whole systems design in creative and collaborative teams (Aldersgate group 2012, IEMA 2014).

### *1.1 Industrial Ecology and sustainability educations*

Industrial Ecology is an interdisciplinary domain of knowledge and can be described as an approach where energy and material flows in industry and society are put in the context of impact on nature. In the 1990 it was acknowledge that in such approach to industrial design needed an education that could "*bridge the traditional separation between the study of technology and society*" (Jeliniski, Graedle et al. 1992). An industrial ecologist is a profession with a competence to assess and bridge deficiency gaps in sustainable problem solving under pinned by systems thinking (Allenby 2006). The typical practitioner use tools such as LCA and MFA to approach the energy and material flows in society. Industrial ecology is taught at master's level at several universities around Europe since the mid 1990'ies for example Trondheim (N), Delft (NL), Graz (AU), Coimbra (P) and Gothenburg (S).

There are several higher education programs with an environmental and sustainability focus such as environmental programs with both social science and natural science profiles, engineering environmental profiles with focus on industrial processes and business administration programs with focus on CSR. Industrial ecology bridge the traditional environmental and business administration programs by applying systems analysis to environmental, technology, stakeholder and actor understanding. An industrial ecologist have the ability to manage transitions in technology and society towards sustainable development (Cockerill 2013)

The objective of this contribution is to improve the understanding on what constitutes the professional role(s) of Industrial Ecologists. An international survey was directed at Industrial Ecologists aiming to chart their jobs, skills and competences. The aim is further to discuss how IE educational programs match the needs of their professional lives with the ambition to discuss how the results can inspire engineering education in general for future curriculum development.

### *1.2 Skills and alumni surveys*

In the literature on skills for sustainable development several concepts are used to describe skills such as, competencies, capabilities and key competencies. To differentiate between skills and competences a useful description from Wiek and Withcombe is "*a competence is a functionally linked complex of knowledge, skills and attitudes that enable successful task performance and problem solving*" (Wiek, Withcombe 2011).

Skills does not work in isolation but in connection to knowledge and experience. The interest in skills is often connected to alumni surveys and employability, relevance in industry and society and feedback to educational programs (Bootsma &Vermeulen 2011, Hansmann et al. 2010, Hesselbart & Schaltegger 2014). Skills that a change agent for sustainable development need to master are such as to be able to persuade, empower and entrepreneurial skills (Hesserbarth and Schaltegger 2014). They also conclude that educational programs need to balance subject specific, methodological issues, social and personal competences with more traditional and conventional based knowledge. In an alumni questionnaire (Bootsma &Vermeulen 2011) evaluated the alumni skills such as ability to translate theory into practice, debating skills, give and receive constructive critique and motivate collaborators. Argumenting, managing conflicts and negotiation and clear communication where among the skills evaluated in an alumni survey of environmental professionals (Hansmann et al. 2010).

## 2 Method

The questionnaire was a web based questionnaire where the link was sent out via e-mail list through program directors and social networks such as Facebook gropes and LinkedIN. The platform used to host the questionnaire was SurveyMonkey. The questionnaire included 60 questions and took 25-30 minutes to complete. The questionnaire was open from mid May to mid June in 2015.

The skills evaluated were communication (oral, reading, writing, speaking and negotiation), academic (analysing, critical thinking, argumenting and change perspective), scientific skills (professional software, calculation, measurement and observation) and personal skills (cooperation, interpretation, self-management, self-learning, managing conflicts, persuade, inspire, empower and decision-making).

### 2.1 Design of the questionnaire and evaluation

The questionnaire was designed according to two main questions: occupation and important activities in their daily work in order for us to be able to evaluate essential competences and skills of a working Industrial Ecologist. The questionnaire was divided into 4 parts:

1. The first part described the educational background, i.e. year of degree, name of M.Sc. degree, and university. In this first part the respondents were also asked to list their weekly activities and how much time was spent on these.
2. The second parts mapped the extent various general skills they used. One part was identifying where different skills were applied in their working activities (*Activities at work*) i.e. with peer, within the company organisation where they work, the local community, nationally or internationally. The other part was mapping communication, academic, scientific and personal skills, and the respondent were to estimate time spent on each as part of their weekly activities, from <1, <5, <10, <15, <20 and >20 hours a week. For each set of skills, the respondents also rated their level of their comfort with each skill (from highly comfortable, quite comfortable, moderately comfortable, I'm doing fine, and not comfortable at all).
3. The third part of the questionnaire covered the engagement with typical Industrial ecology methods and the time spent using the IE toolbox, cross-disciplinary literacy and the type speciality the respondents perceived that their work required.
4. The fourth part covered the respondent's satisfaction with the amount of systems thinking and perception of whether or not they had an Industrial Ecology-type job.

### 2.2. Evaluation of the questionnaire

The resulting excel file was imported to Filemaker Pro were the results of the questionnaire were further evaluated by counting, grouping and characterising the respondents' answers. The answers were in some cases further processed if necessary, i.e. translated histogram information into actual hours where it was useful.

The respondents were categorised based on their application of industrial ecology tools. This was motivated by curiosity and the hypothesis that different skills were important in different types of professional practice. It was also observed that there was a the great variation of tools in use.

## 3 Results and analysis

The questionnaire is estimated to have reached at least 472 Industrial Ecology alumni and 205 responded. The respondents were 52% male, 43% female and 5% would not state their gender. The respondents generally spoke three languages of which at least two were not their mother tongue. The respondents came from 39 countries all over the world from both industrialised and developing countries where the three most frequent countries were Sweden, Norway and the United States. Most of the respondents (66%) were at the time of the questionnaire employed, 2% was unemployed and 32% did not state any occupation. Among the respondents 25% were consultants, 20% PhD students and 12% were project coordinators or managers. Other occupations include eco-engineering, public servants and entrepreneurs.

### *3.1 The responses and identified groups*

Out of the 205 respondents 156 respondents continued to fill in the questionnaire after the initial starting question. The respondents were grouped into 0, >5, >10, >15 and >20 years of graduation and the respondents in the groups were 19, 105, 43, 7, 6 respondents. In the 0-group the majority of the respondents were still students and didn't continue the survey after the first set of questions.

A large group, 40% of the respondents, where LCA specialists for example consultants, PhD students and industry researchers. The larger group of respondents were a mixed group of different type of industrial ecology practices such as communicating, coordinating, supporting and networking activities. The first job after graduation was often consultant, eco-engineer or PhD students and the second were often the same but the consultant has changed to be a PHD student and vice versa.

### *3.2 Activities at work*

It is interesting to study how the Industrial Ecology professions applied different skills in relation to bridge deficiency gaps and translate between different disciplines and professions (figure 1). The respondents could choose more than one alternative in their answer. On a general level the alumni communicate, network and do interdisciplinary work preferably on an international level and to a lesser extent locally and nationally. Peers are generally important and those are found within the company. These peers are probably also international colleagues.

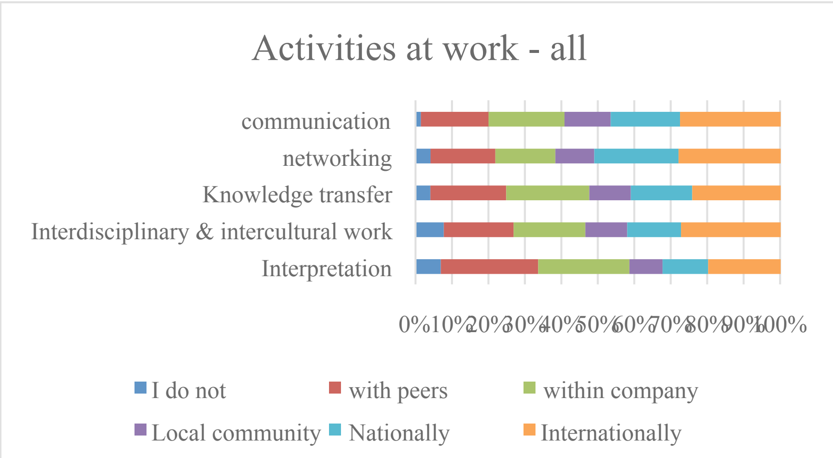



Figure 1. How different skills were applied in the alumni's activities at work.

In comparing the LCA specialist group and the larger more general Industrial ecology practitioners there are similarities and differences. In engaging in Interpretation activities both groups applied these mainly among peers and within the organisation where they are employed and Interdisciplinary communication activities occurred mainly on an international level. A LCA specialist acts more on a national and international level considering communication, networking and knowledge transfer. The other group of Industrial Ecology practitioners communicated and did more networking at the local community level and knowledge transfer appeared more within the company or organisation.

### *3.3 Skills*

The general results For Academic skills show that analysing and critical thinking are skills that the respondents are comfortable with and spend time doing. Respondents spend less time and are quite comfortable Changing perspective and argumenting. In the LCA specialist the group were to a higher degree comfortable with analysing than group with Industrial Ecology practitioner who are slightly more comfortable and spend more time on changing perspective than the LCA specialist.

The results for scientific skills are shown in figure 2. The overall result shows that Professional software was most comfortable and much of the working hours was spent on the software. Looking into the LCA specialist group and the Industrial Ecology practitioner the amount of time and the comfort with the Professional software are perceived equal. Looking further into what type of industrial ecology tools that the practitioners use the group of Industrial ecology practitioners have interpreted this as Microsoft office tools which they spend time on using. The LCA specialist mention to a much higher degree different type of LCA software.

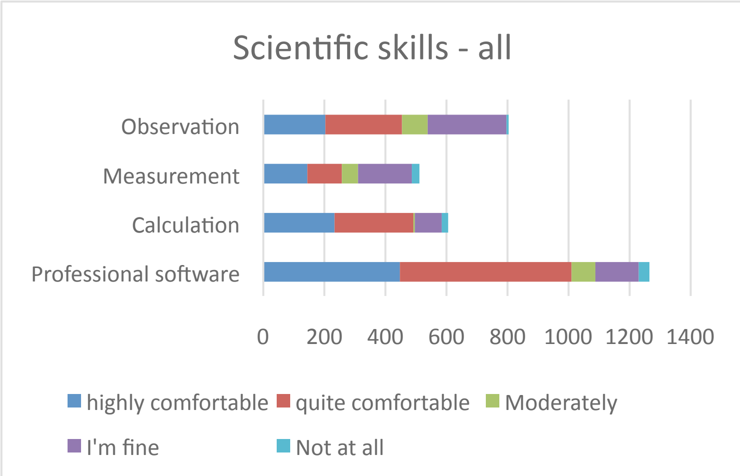



Figure 2. Scientific skills

The results for the whole group of communications skills show that an industrial ecologist is comfortable with reading, writing and speaking and much less comfortable with oral presentations and negotiations. In the LCA specialist group the general pattern was the same as with the respondents as a whole. The Industrial Ecology practitioner revealed slighter higher degree of comfort and time spent on oral presentations and negotiating. By looking into the occupations of the individuals who answered that they were highly and quite comfortable with negotiation and oral presentations showed that these professionals were project managers and coordinators, entrepreneurs and management consultants.

Skills such as cooperation, self-management, self-learning and interpretation are generally perceived as comfortable and decision-making, persuasion, inspire & empower and managing conflicts. The LCA specialists are comfortable with self-learning and less comfortable with Inspire and Empower, Persuade and Cooperation. Looking into the group with high comfort in self-learning you find PhD students, consultants and project coordinators. On the other hand the group of industrial Ecology practitioners are more comfortable with cooperation, inspire & empower and persuade. Looking into the individual answers the respondents with high comfort in persuading and inspire & empower are working as public servants, university teachers, project managers, entrepreneurs and consultants

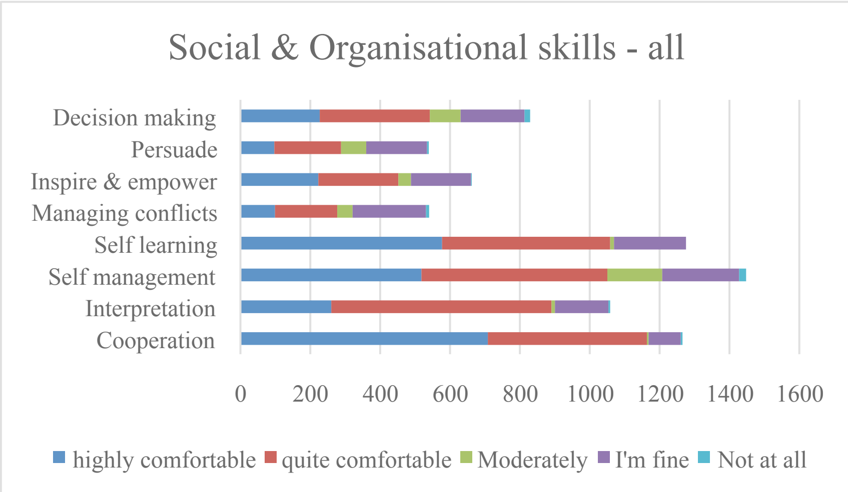
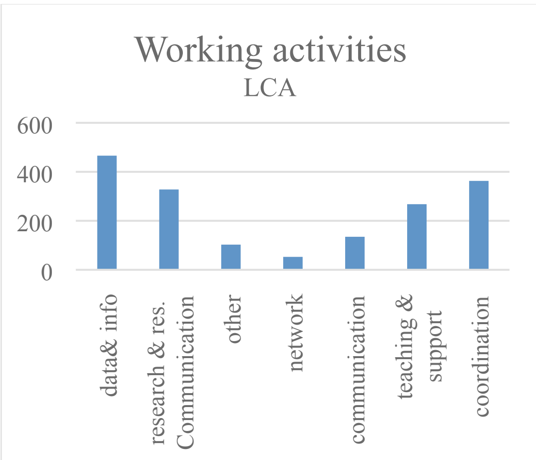



Figure 3. Personal skills and the skills less comfortable are persuade, managing conflicts and decision-making.

### 3.4 Activities at work

The respondents were asked to list the main 5 activities occupying their weekly work. The answers were free text answers that were analysed and grouped into different activities. The tasks that the professionals occupy their time with are finding information and data, research activities, networking, communicating, teaching and support and coordination. In figure 4 the outcome of the activities in the LCA specialist and the Industrial ecology practitioner are illustrated.

Although the group of practitioners are larger than the LCA specialists, the LCA specialist spend more time on data and information. The Industrial Ecology practitioner spend more time networking, communication and coordinating groups. In both groups they spend fairly equal amount of time on teaching and supporting activities.



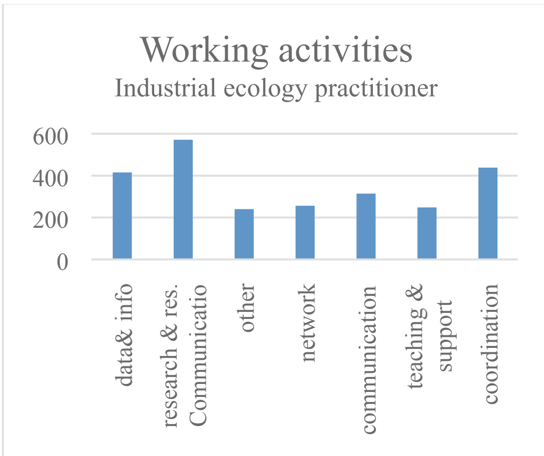




Figure 3. Working activities in the two groups of Industrial ecology professionals

## 4 Discussion

An industrial ecologist first job is often PhD students or a consultant and later on advisor or project leader. This is also found in other alumni surveys of environmental professionals as well as that employers often are consultancy firms, universities, companies and governmental organisations (Bootsma and Vermulen 2011).

From this study it can be shown that an Industrial ecology profile can be described in at least two different ways: the LCA specialist who is a traditional user of the industrial ecology toolbox and the Industrial Ecology practitioner that communicate, network and coordinate industrial ecology activities. These two groups have use of different sets of skills. The task for education it to provide students with the right kind of knowledge, skills and motivation which practitioners need to make difference in the world (Hesselbarth & Schaltegger 2014). At present the LCA specialist is well supported in the educational system.

The two types of Industrial ecology professionals also calls for reflection and review of the curricula in industrial ecology programs. A program that meets both types of professionals need to be truly interdisciplinary where skills are balance between specialist skills and traditional and conventional knowledge (Clark et al. 2011). At present the curricula supports the specific topic expertise i.e. the industrial ecology tool box but not to the same extent the specialisation in a generalist holistic thinking applied to enable the transition towards a more sustainable society. This can be explained by lack of recognition of the skills by the respondents or that the curriculum is taught by specialists as described in Clark et. al (Clark et al. 2011).

The result of this survey should be useful input to improvements in curricula of industrial ecology and other engineering programs to be able to identify islands of specialist knowledge that could be integrated into an interdisciplinary whole. There are educational programs that use alumni surveys to evaluate the education and to get inspired about direction to change (Hansmann et al. 2010). However alumni surveys cannot be the only tool, knowledge about general trends in society needs also to be taken into account. The general trend in industrial ecology and industry is to close energy and material loop in products, cities and industry.

## 5 Conclusion i

This study has identified at least two groups of industrial ecologists, one that has a specialisation in LCA and another group with a much more mixed professional practice. Skills a part of the educational curricula were in general more comfortable to the respondent such as cooperation in group work, analysing data and familiarity with professional Industrial Ecology software. Skills such as negotiation, persuade, managing conflicts get less attention in the educational curricula or rather more perceived as a skill taught by life.

The focus in industrial Ecology programs are in general on the industrial ecology tool box and preferably LCA. Industrial Ecology is developing into new arenas where lifecycle thinking and systems thinking guide the practitioner in the day to day practice where daily activities focus on managing stakeholders, coordination of actors and managing networks. These new arenas of practice for Industrial ecology and engineering in general have potential for development in the industrial ecology curricula.

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# Internet Platforms for Education on Sustainability

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### Abstract

Teaching in general and teaching sustainability aspects in various disciplines specifically can be facilitated by recording the lectures on video. The videos can then be shared not only with the own students but across universities, especially, if the accompanying teaching material like manuscript and PowerPoint presentation are shared simultaneously. The video recording actually leads to an increased quality of the lecture as a whole, including the lecture material. Especially for sustainability topics, such fully worked out and shared modules could augment existing curricula or lectures to the best possible educational outcome. A platform would be desirable for sharing these materials, based on standards, on which the contributors previously agreed.

## 1 Introduction

One challenge in teaching sustainability results from the expertise being distributed in various universities. At the same time, society would not require so many experts focused on sustainability that corresponding purely sustainability-oriented curricula should be offered in a majority of universities. Thus sustainability aspects have to be integrated into existing curricula e.g. in chemical engineering studies. To offer sufficiently high-level courses or teaching content, one way is to share modules dealing with sustainability aspects between different universities, developed and presented by the corresponding experts in the field.

The idea to share teaching capabilities on a national or international level is not new. One example is sustainicum (2016), where several Austrian universities share teaching material on an internet platform. For many of the available modules the authors just supply PowerPoint presentations or manuscripts. Unfortunately, the material is supplied mostly as PDF, which in turn means significant effort, if the module should be presented at another university. A certain limitation also results from German being the major language on that platform. Looking for teaching resources it also appears that the offered material has very different scope, some resources relating to entire courses, some to just an individual minimalistic aspect.

Consequently, a more systematic approach in view of building up a proper curriculum or a significant contribution to curricula would be desirable.

In order to facilitate delivering the corresponding module, the author has recorded videos of the presentations prepared, for which the PowerPoint slides as well as the manuscript have also been made available in the original format so that modifications are easily possible (Pfennig, 2013). The videos have been uploaded to YouTube to ease access.

Another example is BioEnergyTrain (2016), which corresponds to a European consortium including several universities and companies. The goal of BioEnergyTrain is to develop sustainability curricula as well as the corresponding teaching content, especially for Biorefinery Engineers and Bioresource Value Chain Managers. Elements of generating the curriculum and module content are e.g. summer schools, think tanks, and labs performed in industry. Unfortunately, BioEnergyTrain does not deliver the results directly to the public, i.e. only site members have access.

While these approaches address the topic of sustainability with a relatively wide variety of facets, it is difficult to see, how a coherent picture can be obtained and transferred in education to students and the interested public.

## 2 Exemplary topic

While this is so, already regarding the most basic element of the versatile toolbox of chemical engineering, namely setting up and solving simple balances, leads to significant insights and especially a fundamental understanding on the basic interplay of at least some of the major drivers. These are – besides increasing world population, which is the main driver – the increasing energy consumption, the limited land area for food, biomaterials, and bioenergy production, the finite size even of the atmosphere leading to an increase in $CO_2$ concentration and climate change, to name just a few. All of these aspects refer to limited resources for which balances can be set up and solved. The balances have the advantage that they are so simple that everybody can assess their validity and the resulting implications. These insights are not just relevant for corresponding curricula but are also of social relevance as well as could contribute to more knowledge-based decision-making by politicians.

Based on the corresponding balances the major interacting factors have been related and corresponding teaching material worked out (Pfennig, 2013). As an example, the interplay between land-area use and food supply is shown in Figure 1, which is taken from the English version of that presentation. This diagram summarizes the results of corresponding balances, which are worked out in the presentation in such detail that also the non-engineer can follow in principle. This means directly that sufficient care has to be taken to introduce the corresponding concepts without requiring previous knowledge on the topic. In this presentation, also the conceptual basis for balances is developed and explained, starting from the simple example of a purse but also applying it to the radiation equilibrium between sun and earth determining earth's average temperature as an introduction to dealing with climate change. For this presentation, the comprehensibility has been ensured by testing the presentation at public schools as well as on the dies academicus, i.e. open university days for introducing interesting topics to the interested public and potential future students.

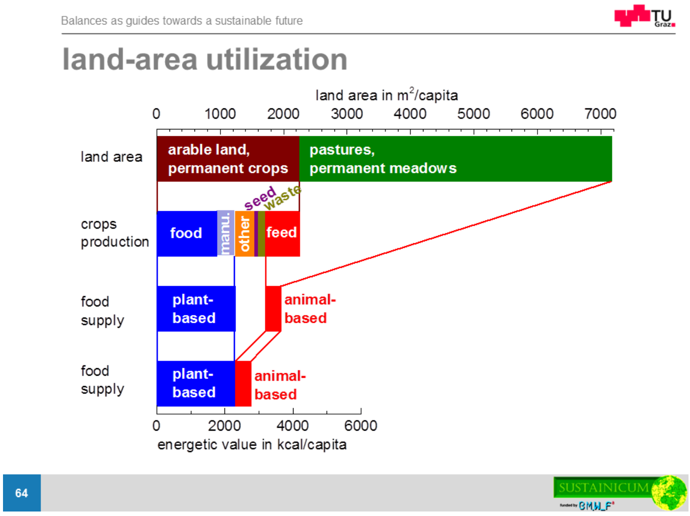


Figure 1: Relating land-area use and food supply.

The simplicity of these balances and the clarity of consequences resulting from regarding probable scenarios of future development are intriguing. It is believed that being aware of these balances and the orders of magnitude of the various contributions may lead to significantly more relevant social and political discussions. If e.g. the orders of magnitude of the material basis of human life are regarded as shown in Figure 2, it becomes obvious that discussing about avoiding plastic bags or the secondary energetic use of spent motor oil are referring only to marginal aspects, i.e. actually other contributions could lead to significantly more impact for minimizing the use of fossil resources. On the other hand, it also becomes obvious that the major driver, namely the increasing world population as the actual problem to be solved is rarely properly addressed, in influential publications even fundamentally denied (§50 of Francis, 2015). If society were more aware of the basic balances, such fallacies could be avoided.

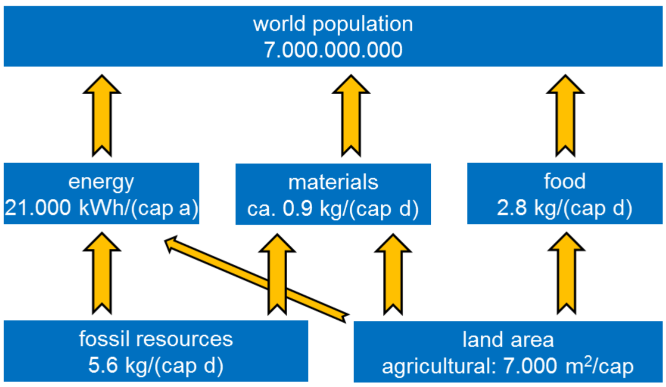


Figure 2: Interaction of some major drivers (Pfennig, 2016).

## 3 Video Recording

Along a different line of personal development, first own lectures have been recorded by the author since of the order of 10 years. These videos were originally recorded during the ordinary lectures with little effort hardly edited and supplied to the students on corresponding intra-university teaching portals. The videos were intended to support the students in their studies, e.g. allowing them to watch the lecture again shortly before the exam e.g. on specific topics they realize as problematic in the exam preparation. The media used during lectures at that time were the blackboard for developing all theoretical aspects of the lecture and PowerPoint slides for any accurate graphical representation or photographs shown. Consequently, the videos were good for the intended goal but had little reach beyond this.

Regarding the effort to be put even into this simple recording and the parallel development of the videos of the sustainicum presentations mentioned above, the decision was then obvious that in the future the lecture content should be recorded only once in sufficiently good quality. During the first attempts with video recording different set-ups were tested and lectures available on the internet evaluated. Some colleagues e.g. present all material on a tablet laptop, the screen of which is recorded together with the voice of the lecturer. While this is easily realized, this setup minimizes the personal interaction between the lecturer and the observer, because the lecturer is not visible. It appears especially difficult to deliver any enthusiasm for a topic, if face and gesture are not recorded. Then it was tested, if the setup using a blackboard together with PowerPoints could be optimized, which failed, because proper illumination of all elements was not possible simultaneously. The same problem arose, when the presentation was delivered on a tablet laptop being projected with a beamer. In that setup the lecturer can be recorded together with the projection, but either the lecturer appears too dark or the projection is overexposed. The media experts then proposed to use green-screen technology, sometimes used on TV, because then each individual element can be optimally illuminated. Since this requires significant practice, this suggestion was not followed further. With the support of the media experts at TU Graz the final setup was then realized, which allows good results. Later a similar setup was realized at the University of Liège in the studio of the Institut de Formation et de Recherche en enseignement supérieur (IFRES).

The final setup shown in Figure 3 uses a convertible laptop for delivering the lecture, where the slides are shown as PowerPoint presentation. The text e.g. for derivations are presented as Windows Journal file, where prior to the lecture an empty document with a sufficient number of pages should be created because this eases scrolling. Care should be taken that the tablet is equipped with a directly accessible key that allows either switching between open applications or that opens the task bar to maneuver between the PowerPoint and the Journal file. In addition, a digital pen should be used that allows easy erasing, preferably with the rear end of the pen. The screen is then displayed on a large TV screen of e.g. 70 inch diagonal. The screen should also not be of excessive size to allow easily pointing at the different locations on the screen. The lecturer can then present the diagrams and photos on the screen, actively interacting with the content. The derivations and other text are written on the tablet screen, which the author places on a Curver box turned sideways (see Figure 4), which is also used to transport the required material to the lecture room. A lectern would be preferable, but in many lecture rooms, the box placed on a table is a good solution. The lecturer is illuminated by one or two spotlights, e.g. 50W LED spotlights found in ordinary hardware stores with appropriate stand. Alternatively, comparable professional spotlights can of course be used as seen in Figure 3, where actually only the right ones are used in video recording, because the left one causes reflections on the TV screen.


Figure 3: The chosen recording environment, where the Curver box underneath the convertible is omitted (photo reproduced with permission: © Olivier Borsu, IFRES - ULg, 2016).

The video is recorded with any suitable camcorder of at least HD quality, for the sound recording a clip-on microphone and a 24-bit wave/mp3-recorder is used, e.g. Roland R-09. The reason for recording the audio track separately with 24 bit resolution is that selecting the proper recording level without loss of signal-to-noise ratio is greatly facilitated. The audio track is then optimized with level adjustment, slight compression and conversion to a 16 bit mono track with the open-source software Audacity, available at http://www.audacityteam.org/. Joining video and sound track as well as final cut can then be realized with any suitable software. At the University of Liège Pinnacle Studio is available, which has been used for the latest videos. Synchronization is facilitated by a hand clapping at the beginning of the recording. If cuts are to be made, hand clapping is also a good way to mark the positions, because their position is later easily seen in the audio track. The final video has a resolution of 1920 x 1080 pixel with 24 frames/s, the audio is mono with 16 bit, 128 kBit/s. The overall bitrate is 2000 kBit/s with mp4v-codec.


Figure 4: Screenshot of a final video.

An example picture from a video is shown in Figure 4. Care is taken that the individual videos are of proper length, i.e. mostly between 20 and 30 minutes. Only in exceptional cases, up to 45 minutes are recorded, where individual derivations require this.

After recording, the video is uploaded to YouTube, but alternatives like Vimeo are possible as well. These platforms allow various additional features like using sub-chapters, adding the content of the slides as searchable text, or active interaction with the community. The author currently does not use these additional features, because of the additional work effort.

Since the lecture is recorded, significantly more care is required for working out the individual chapters. E.g. consequently including slides with the chapter headlines, slides with take-home messages at the end of each chapter, using most appropriate and up-to-date pictures for visualization, and including sufficient and appropriate color in the diagrams are some aspects to be accounted for. Also the manuscript should exactly match the content of the lecture and sufficient care needs to be taken to really transfer the exact logical structure, i.e. arguments mentioned need to be exact and complete, where in usual lectures hand-waving or plausible arguments sometimes might have been sufficient. This of course also greatly supports the quality of the live lectures as well. A difficulty to be mentioned is that for the videos to be made available to the public, the copyright issues need to be clarified before using any diagram of photo. Experience shows that a lot of material can be found on Wikipedia with sufficient quality and sufficiently flexible copyright rules. Other material, like e.g. YouTube videos or diagrams from other web pages need individual consideration, but also here experience shows that while being tedious, generally the right to publish is granted by the copyright holder after a simple e-mail briefly explaining the project.

The quality of the final videos is such that the videos can be used in teaching directly. The author in the past actually applied this in some exceptional cases of urgent absences. Proper care should be taken that in such cases questions occurring to the students can be asked and answered e.g. by a teaching assistant present or during the next live lecture. Daring to view into the future, it can of course be envisaged that the students are required to view the videos at home – since they are recorded at the best educational level – and only Q&A sessions are offered occasionally. This is a picture slightly reminding the author of a situation in the movie "Real Genius" of 1985, where the students successively left their recording device in the lecture room until after some lectures no live student was left, so that the next time the lecturer also was replaced by a magnetic tape.

## 4 Conclusions

As a general conclusion, it is found that recording the lectures in a studio enhances the quality of lecture material and thus the lecturing as an important side effect. The videos together with the matching manuscript and the PowerPoint presentation allow easy transfer of the material. For sustainability topics, a corresponding platform, possibly as YouTube channel with links to the lecture material, or a dedicated platform would be desirable. As a result from evaluating some existing similar platforms, a general agreement on the quality and scope of the contributions would be required, which is then defined as standard, which is checked. With such a platform, a variety of high-level sustainability teaching modules could be collected to be used in teaching at various universities with minimal local effort. Such a platform would allow sharing educational means worked out by the experts in the field on the highest possible level fitting to a variety of curricula, where sustainability could otherwise not be taught appropriately or only with significant additional effort.

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# Active Learning as a Supportive Teaching Method to Address Climate Change in Higher Education

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## Abstract

This study investigates if active learning methods can help universities support students, when teaching climate change in higher technical education. Data for the research is collected through three case studies of interactive seminars in climate related courses at *the Royal Institute of Technology in Stockholm*, KTH, as well as at *the University of Graz*. The active learning is facilitated through gaming sessions with a climate board game, containing exercises in vocabulary, as well as explanations of the physical science basis.

Analysis of survey responds (n=102), mind-map reflections (n=14) and interviews (n=5) led to the development of three key findings: (1) students' attitudes toward scientific climate communication involves emotions which advisably should be taken into account in climate education, (2) the proposed active gaming seminar have effects on students' understanding of climate change, mainly thanks to the interaction and possibility to discuss with peers, (3) students' confidence - in their own understanding as well as in their ability to explain climate change - increase, owing to the active learning method.

Moreover, the results in this study indicate that universities could play an important role in climate communication, since a university provided introduction to climate change can "push the students over a threshold", so that future participation in discussions on the topic become less distant. Using games as an active learning tool can, with other words, increase student understanding and confidence in the topic of climate change - and doing so in a supportive and enjoyable manner.

## 1 Introduction

Anthropogenic climate change is gaining more and more recognition in the world. Elizabeth Sawin, Co-Director of the awareness rising organization *Climate Interactive*, underpin the future's need for "multisolvers" - collaborative and system-thinking individuals - to manage innovations needed for climate change mitigation and adaptation (Sawin 2015). Much confidence is put on green technology and the industry's recent launching of "Solutions Revolution" during COP21 is one sign of the ever-growing expectations on engineers' capabilities to solve complex, sustainability related challenges (World Climate 2015). Ordinances at international[1] as well as national[2] levels intend to improve the education for sustainable development and *the Royal Institute of Technology* (KTH) is one of the many universities working actively with improving the education for sustainable development (Finnveden & Strömberg 2013; ISCN 2016). However, a KTH education assessment from year 2011 stresses that sustainable development aspects require yet more attention to meet the demands of the labour market (KTH 2011).

[1] UN Decade of Education for Sustainable Development

[2] Swedish Higher Education Ordinance

Universities aiming at improving their climate education as part of sustainability education may, however, face general challenges of climate communications. Communicating climate science to non-specialists is problematic; complex findings are difficult to simplify and the way scientists communicate does not align with the way most people receive information (Lynn 2016). The reports from *the Intergovernmental Panel on Climate Change* (IPCC) – including the summary for policy makers – have been criticized for being hard to understand and use. In February 2016, the IPCC held an expert meeting to provide recommendations on communication work for the sixth, upcoming, assessment report. One conclusion from the meeting is the recognition of a legible role for third parties to communicate the contents of the IPCC reports. Knowing the addressed audience is important in communication, third parties could contribute with understanding of local audiences and by using a type of communication suited to the situation – therefore complementing the scientific, credible messages of the IPCC (Lynn et al., 2016). This indicates a need to explore ways in which universities could educate the future problem solvers and decision makers, now studying at their universities.

If drawing parallels to climate communication guidelines, developed to educate people about climate change outside the academic world, universities might as well encounter challenges in communicating the findings of climate science as it must tackle limitations of human risk management; it is a struggle to balance future concerns and immediate threats. A consequence of restricted risk perception is that motivation to take action for climate mitigation and adaptation not solely occur from understanding the graphs of the IPCC (Center for Research on Environmental Decisions 2009). Steel and König (2006) argue that the time-discounting function of human behaviour must not be forgotten when trying to understand processes of decision making and prioritisation. According to their *Temporal Motivation Theory,* courses of action can be easier understood if expectancy of reward, as well as the supposed delay to the reward are taken into account. In the context of successfully reached learning outcomes in climate education, this implies a need for consciousness when choosing teaching strategies.

In the literature on teaching strategies, scholars are debating the learning effects of various methods; amongst others whether *active learning* is a better alternative to traditional lecturing or not (Freeman et al. 2014; Hora 2014). Active learning is used as a broad concept for teaching techniques which encourage student participation and emphasis development of students' skills, rather than merely focusing on information transmittance (Keyser 2000). Freeman Herreid (1998) argue that students learn more if enjoying studying, explaining ideas to one another and getting peer support, than if only listening to lectures. Moreover, a meta analysis of 225 studies, in which active learning and traditional lecturing are compared, suggests an increase in student performance as well as a lower odds ratio for failing (Freeman et al. 2014).

Along this line, it has become increasingly popular to develop games as an active learning tool for sustainable development education (Katsaliaki & Mustafee 2015). In accordance with this, one of the existing sustainability course modules at KTH, introducing the topic of sustainable development, is successfully facilitated by using board games (Dahlin et al. 2013). One reason for using games in educational purposes is that gaming can help increase understanding and enhance student knowledge (Katsaliaki & Mustafee 2015). Games and simulations are particularly interesting when aiming at translating scientific results into a language understood by the general public (Reckien & Eisenack 2013). Within the field of games addressing climate, Wu and Lee (2015) illuminate a couple of areas with a lack of research. Amongst other suggestions for future studies, they invoke further research on whether climate games have influences on players' attitudes towards scientific explanations of climate processes.

This study aims to investigate if active learning methods can support student learning of climate change in higher technical education. A board game, designed to provide familiarity with the IPCC messages and its scientific approach, is used to facilitate active learning in the three cases conducted within the study. Surveys, mind-map analysis and interviews are used to collect data in three various student groups. The study does not examining whether education leads to individual behaviour change, neither is it comparing active learning with traditional teaching methods. Instead, this study is focusing on (1) students' attitudes toward learning about climate change, (2) the effects of the proposed active gaming seminar on students' understanding of climate change and (3) students' confidence, in their own understanding as well as in their ability to explain climate change.

## 2 Methods

Data for this study is collected from three student groups in higher education from different fields of studies. Group "Graz" consists of students who electively have chosen to participate in a seminar course, after participating in lectures of a 3 ECTS lecture course, but before being examined. The lecture course is called *Earth's Climate System and Climate Change* and is provided by the *Wegener Center for Climate and Global Chang*e at the University of Graz, Austria. The interactive seminar course is worth 1.5 ECTS and consists of two occasions of playing a climate game (briefly explained in the next paragraph). The students taking the seminar course come from various studying fields, most of them being *Industrial Ecolog*y students. The, so called, "CL-group", on the other hand, are first-year students of a five year engineering program with pedagogy as a major field, provided by KTH in Stockholm, Sweden. A 90-minute online preparation followed by an interactive seminar constituted as an introduction to the topic of climate change, as part of a broad introduction course called *Physics, Chemistry, Energy and the Environment*, worth 15 ECTS. The third group, called "Titeh", are first-year students to a three year engineering program with technique and economics as major fields, also provided by KTH. For this group a 90-minute online preparation followed by an interactive seminar worked as an introduction to project group works, linking the topic of climate change to business and investments.

A climate board game called *Clime-Out* is used as an active learning tool, which means that discussions and interactivity is facilitated through gaming in groups of 6 students. The game is purposely designed, with the aim to familiarize the players with climate change science as well as a scientific working procedure. One part of the game consists of explaining relevant vocabulary, another is focusing on scientific explanations of climate processes. The latter is carried out as the players, in turns, take the roles as researchers, reviewers and "curious", and together interpret and digest selected parts from IPCC reports.

Throughout the study a combination of qualitative and quantitative methods is used to gather data from the three student groups' climate education, namely: surveys, mind map analysis and interviews.

**Surveys:** Questionnaires were filled in by the students before, as well as after the seminars. The surveys included space for free comments, but were mainly designed with statements, to which the students were invited to respond their level of agreement (Likert Scales (O'Leary 2004)).

**Mind map analysis:** With inspiration from concept mapping and the assessment methods used by (Segalàs Coral 2009) a mind map method was developed. Students in the Graz-group had five minutes to draw a mind-map before the first seminar began and, likewise, at the end of the second seminar. As part of the seminar course the students were asked to write a reflection on differences and similarities in the two mind-maps.

**Interviews:** One focus group and two semi-structured interviews were conducted with randomly selected students. The quotes originally written in Swedish are freely translated by the author.

## 3 Results

### *3.1 Students' attitudes towards learning about climate change*

Interview findings in this study suggest that with demand to learn about climate change, the first question of a first year engineering student will be: "why should I learn this?". The interviewees from the CL-group explain a constant challenge of prioritization between math courses and other courses; unless seeing a clear reason or profit to study something else, math will always be prioritized. Moreover, the interviewed students suggest a distinction between the "common" engineering student and the "environment-interested" student. Students who have chosen an education program that is specialized on sustainability are thought to have an "inner motivation" to learn, whereas others may neither have the personal interest nor think of sustainability as something their future employees will demand. This points toward a motivation stemming from anticipated future job opportunities and/or employer demand.

One primary hypothesis of this study was that the student's thoughts in how humanity will manage climate change would affect their will to work with something climate related in the future (e.g. only students with a vision of successful management of climate change would want to contribute by working in this field). However, the survey answers (Figure 1) suggest no correlation between how the student answered to the assertion "*I think that humanity will succeed with handling the climate change in a good way*" and "*I want to (in one way or another) work with climate issues*". This is shown by the linear trend line in Figure 1, and the correlation is further invalidated with a low coefficient of determination ($R^2$=0.00125).

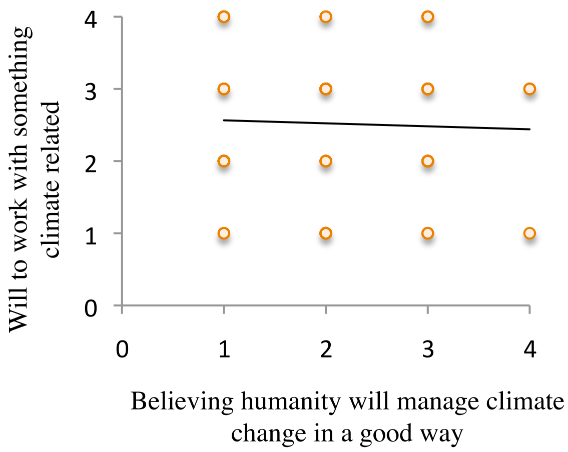


Figure 1 Will to work in the field plotted against same student's vision of successful management of climate change. The statements are answered on a four-point Likert scale, in which 1 means "totally disagree" and 4 means "totally agree". Data is collected from a post-survey answered by 52 students in group CL.

Due to the lack of a simple explanation of which students who want to work with something climate related in the future – hence finding more motivation to learn about climate change – the various mind-sets were further explored, based on responds to multiple contextualized statements, inspired from the temporal motivational theory. Table 1 presents an attempt to cluster student attitudes into four groups, with correlating subgroups, based on their responds in a four-point Likert scale. Although some respondents seem hopeless regarding the future quality of life, the underlying reasoning (shown in Table 1) varies. Interview findings indicate that universities teaching about climate change must bare in mind that first-year university students are young enough to have been brought up with awareness of global environmental problems, concern for the consequences of Antropocene is already part of those students' lives.

Table 1. Student mind-sets in believing humanity will manage climate change in a good way and their own involvement, clustered into four groups. Groups are formed based on survey responds to 5 assertions in the post-survey, which more or less directly address motivation towards working with climate. The statements are adapted to represent temporal motivation theory regarding vision of overall success, will to contribute, confidence in improvement by personal contribution, delay of improvement and general tolerance for delays. Data from 52 students, group CL.

| Mind-set | Reasoning | Percentage of students |
|---|---|---|
| "It won't work. I | "No use even in trying, what could I do anyway?" | 12 % |

| | | |
|---|---|---|
| don't want to try." | "I could probably do a small change, but I'm not interested and it won't work anyway." | 19 % |
| "It won't work well, but we have to try." | "I want to tell my grandchildren that I tried, but I won't be able to change things." | 13 % |
| | "We (and I) can make it less bad!" | 25 % |
| "Others will manage it. I can focus on my other interests!" | "I can't contribute, but humanity will manage it just fine." | 4 % |
| | "Humanity will manage it, I could have been part of it but I have other plans." | 10 % |
| "We'll manage it. Let's begin!" | "We'll make it eventually, let's begin!" | 10 % |
| | "We'll make it! It will work faster than we think, so let's begin!" | 8 % |

One of the focus group discussions took departure in the view that media reporting on climate change at least not could harm people's attitudes towards climate change explanations. However, the discussion proceeded to the following conclusion: commands without sufficient explaining information get interpreted as "nag*"*. Too many commands, concerning what is good and bad for the environment, leads to a fatigue and "spammed" feeling. Another interviewee also reflected on the different emotions awoken by university versus media delivered information: the inference was that scientific explanations lead to understanding of *why* things are happening, whereas, information in the media awakes *feelings*. Recurring in all interviews, as well as in post-surveys, is the experience that climate education, provided by school or university, can force students to deal with their "nagging pain", caused by exposure to constant information flow but never seeking a trustworthy source. The interviewed students mean that climate information reaching them in every day life is of a kind that they always take critical stance to. Hence, they experience a relief by – more or less reluctantly – working with what they call "real" information. As part of further discussion in attitudes towards how the science of climate processes is explained, the interviewees brought up the important role of the communicator as a person. More than once *An Inconvenient Truth*[3] was mentioned to have worked as a wake-up call – thanks to Al Gore's authoritative voice and the accessibility of his film on the Internet. The interviewed student meant that less famous communicators need credibility and transparency; more specifically that would mean "practicing what they preach" and not risking losing trust of the students by trying to work around the psychology of the students.

### *3.2 The effects of the active gaming seminar on students' understanding*

All 14 students drawing mind maps before and after participating in the interactive seminars, themselves identified differences in their two mind maps. No student identified degradation in their mind-maps, but some weaknesses of the method were mentioned, e.g. that short time memory made it easier to draw the second mind map, since it was drawn straight after the gaming session. Student observations were clustered into subcategories and eventually matched to three main categories, inspired by indexes used in concept map assessment by Segelàs Coral (2009) (Table 2). Following quote is picked as an example of the many similar student reflections, stating that the active way of learning helped to put the new knowledge into words and context:

> *"After hearing the lecture and before the first gaming session I thought I had an acceptable overview of the current climate system and its ongoing change. Sadly I was not able to create a proper mind map due to my lack of vocabulary and inability of linking the keywords. So I had a bit of a struggle with my first mind map which led to*

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3 Documentary from 2006 with director Davis Guggenheim (IMDb 2006).

> *some doubts about my self assessment. After the second session and thanks to the "Activity" gaming style my vocabulary seems to have improved and linking the major keywords was easier thanks to the previous "scientific" questions. In our group, these questions tended to escalate into long lasting discussions.".*

Table 2 Categorization of students' observed differences, when comparing their own mind map drawn before the interactive seminars (mind map 1) with that drawn after (mind map 2). Data from 14 students in group Graz.

| Main categories | Subcategories |
|---|---|
| Number of concepts | Mind map 2 includes more words |
| | Mind map 1 seems narrow compared to mind map 2 |
| | Mind map 2 has more number of concepts per category |
| Number of connections | Links and associations in mind map 2 are more sophisticated and sound |
| Relevance of concepts | Mind map 2 gives a clearer and more accurate picture |
| | Something is forgotten or avoided in mind map 1, that is mentioned in mind map 2 |

The interviews, open-answer questions and comment space in the post-surveys were helpful to collect students' reflections on the reasons behind the learning outcomes (Table 3). If negative aspects were raised, they were often followed by concrete improvement suggestions, complains about the teaching method were only to be found in the pre-survey. For example, one student in the CL-group comments: "*For me, who is not so interested and conversant with the issue of climate change, I think it is better with lectures than having to actively participate in a seminar on the subject*.".

Table 3 Frequently mentioned outcomes as well as students' analysis of reasons behind the outcomes. Data is compiled from open questions and free comments in the post-surveys from all groups (Graz, CL and Titeh).

| Frequently mentioned outcomes | Frequently mentioned reasons to the outcomes |
|---|---|
| - Learn and gain new insights<br>- Deeper understanding and practise knowledge<br>- Understand complexity better<br>- Clarify knowledge gaps | - Interactive<br>- Discuss with peers (additionally for Graz: positive that peers had various backgrounds)<br>- Learning by doing<br>- Learn in a way that is not difficult |

The interviews enabled increased comprehension of *how* the active learning as such impacted the learning process. The use of board game is mentioned to have created extra motivation, since the students were focusing on winning and did not think about that they were studying. The interviewed students concluded two outcomes from not thinking about that they were studying: on the one hand it extended their attention span and on the other, it made them enjoy learning about climate change.

Throughout the interviews, the importance of explaining with own words, or listening to a course mate's explanation, were emphasised. The activity was said to avoid a lecturer trying to communicate something the students anyway did not understand, and together the students felt more able to interpret questions. One informant expressed that the discussions about interpretations and views felt utterly important, adding that an awareness of others' perspectives feels crucial in order to proceed with eligible climate solutions. Moreover, interview results suggested that the multifaceted discussions and exploration of the topic's complexity worked as an opposite pole to some encountered oversimplification experienced in media. Some interviewees had never heard of the IPCC before, and one is reasoning about the obvious need for pre-knowledge to be able to understand the information: "*if you don't have any pre-knowledge it's like a stone wall*".

### 3.3 *The effects of the active gaming seminar on students' confidence*

Data from the population of students participating in this study suggest that active learning methods can facilitate a decoupled growth in the students' perceived increase in understanding ($\Delta$=0.29) and confidence in explaining climate change ($\Delta$=0.50) (see Table 4).

Table 4. Total mean value of students' perceived understanding of climate change as well as confidence in explaining climate change. The results are from surveys before and after the interactive seminars and are expressed with a number between 1-5. The standard deviations were analysed for the confidence interval of 5 %. All groups (Graz, CL and Titeh).

| Group | Mean before (n=93) | Mean after (n=102) | Δ All groups |
|---|---|---|---|
| Perceived understanding | 3.12 ± 0.9 | 3.41 ± 0.82 | +0.29 |
| Confidence | 2.92 ± 0.95 | 3.42 ± 0.92 | +0.50 |

In one of the mind-map analysis a student revealed the attempt of trying to avoid certain topics in the first mind map, since not being sure about them. The interviewees described similar experiences, and explained a feeling of having been pushed over a threshold during the seminar; once they had been "forced" to discuss climate change they felt more confident in new discussions. Roles in the games enabled a dynamic, making it acceptable not to fully understand or be at the same level, but still being able to cooperate by challenging the others' knowledge by asking questions. One interviewee witnessed a lot of discussions after the seminar: the students discussed different views, opinions and shared tips on climate related videos on the Internet. They even started to discuss what they had learnt earlier on in the on-going introduction course, the interviewee expressed it: "*It became more like: 'this is perhaps not the world's most boring topic, maybe it can even be a bit fun'*". As reasons behind the changed perspective, the free space during the game sessions was mentioned. The interviewee had a feeling that it was less "*confined*" and compare the experience to other seminars when the students can get a feeling of being "*watched over*" by the teacher – a feeling, which leads to less openness towards saying "*wrong things*" and having "*weird opinions*".

## 4 Discussion

The analysis of students' attitudes toward learning about scientific climate processes is suggesting that university education about climate change involves emotions. The mind-sets of students, shown in Table 1, are in line with more extensive Swedish studies on the emotions young people have; one study is suggesting that 29 % feel hopeless towards the global environment problems (Ask 2016) and in another study 79 %, of the 1000 respondents, reported to worry about how climate change will affect the world and their own future – one quarter even stating stomach pain or unhappiness when thinking about climate change (WWF 2013). These emotions emphasis the challenging art of climate education, and can be understood as a need to strive for student support, but also to address the *relevancy* of how the students future professions could be part of climate change mitigation or adaptation. Although the university sees a need for sustainability knowledge on the market, students might not find it relevant to their future work, therefore being unmotivated to learn about the topic from the start unless – if applying temporal motivation theory (Steel & König 2006) – seeing future and/or immediate possibilities of rewards.

The choice of words when one of the interviewees describes the common fear of saying *"wrong things"* and having *"weird opinions"* if a teacher is around, highlights the difficulty of avoiding normativity when teaching about climate change. The aspect of how to achieve pluralism in education for sustainability is currently being discussed by practitioners (Ask 2016). To further understand how to avoid normative teaching, this study suggest that it is important that the university is transparent with the reasons behind the chosen way of communicating climate science; any psychological "trick" used, should be clarified to the students to avoid distrust and the reactive student feeling of being "nagged at". As regards the importance of knowing the audience in climate change communication, the facilitation of letting the audience communicate in the audience's own language could perhaps be used as a short cut to ensure appropriate communication and avoid the feeling of normativity.

The categorization of students' observed mind map differences, in Table 2, shows the effects that the active gaming seminar had on students' understanding. Although the mind map method has its weaknesses (few partaking students, not excluding the aspect of short time memory contribution, etc.) the students' observed mind map changes are similar with previously used concept map assessment indexes such as number of concept, number of connections and relevancy of concepts (Segalàs Coral 2009). One could argue that if the engineers are the future problem solvers and decision makers, they also have to be prepared to receive updates in climate research. The interviewee, comparing first time exposure to an IPCC report with hitting a "*stone wall*" (Section 3.2), illuminate one important role universities can play in climate communication. Whether the university is being a third-party communicator of the compiled research results in the IPCC reports, or also presenting its own climate research, the future professionals might feel empowered to utilize *the Summary for Policymakers*, if climate change education is being wisely integrated in the curriculums. Pushing the students over the threshold to discuss climate change – as well as providing for increased *ability* to discuss – are in this study suggested to be strategies to involve when aiming to enhance student confidence.

## 5 Conclusion

As with any pedagogical tool there are benefits and drawbacks. This study, however, suggest that active learning through gaming is one possible teaching method, which helps universities to support their students when teaching climate change in higher technical education. An analysis of students' attitudes towards climate communication is important for maintaining students' trust and would advise educators on how to address 'climate change' in a way that is relevant to the students. An active learning method containing student discussions can contribute to improved understanding of explanations of climate processes, partly since the peer-to-peer communication moves away from the idea of one single communicator explaining something that students may interpret as normative commands.

Moreover, the results in this study indicate that universities could play an important role in climate communication, since an introduction to climate change can "push the students over a threshold", so that future discussions on the topic become easier to comprehend. Using games as an active learning method has the potential to increase student understanding and confidence in the topic of climate change – and doing so in a supportive and enjoyable manner.

## 6 Acknowledgments

We thank Maria Malmström for sharp-sighted review and improvement suggestions for this paper; Gottfried Kirchengast for invaluable cooperation and sharing of knowledge; staff and teachers at KTH involved in the execution of the interactive seminars.

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# An Edible Education in Sustainable Development Part 2: Investigating Chocolate Manufacturing in a Laboratory-Based Undergraduate Engineering Course

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## Abstract

Green chemistry and engineering, sustainability, and cyclical economy are topics of great import to all engineering disciplines. At the 2015 EESD conference in Vancouver, our strategy to increase student awareness and understanding of these topics related to the production of chocolate truffles, including the impact engineers have on socioeconomics, in a laboratory-based undergraduate engineering course were presented. Preliminary results indicated that the course was effective in enhancing student knowledge and awareness of the social and environmental implications of chocolate manufacturing. Similar to last year, students this year learned to produce chocolate truffles and were ultimately challenged to analyze and optimize the sustainability of chocolate manufacturing using cradle-to-gate and life cycle assessments. Student analyses incorporated waste management strategies, overall energy and material consumption calculations, good manufacturing practices, carbon reduction strategies, the use of engineering software, and the social implications of fair trade in the chocolate industry. This year, 113 multidisciplinary first year engineering students at Rowan University partook in an updated version of this course. Revised experiments, activities, and pre- and post-tests were utilized to evaluate whether the course increased their knowledge of green chemistry and engineering, sustainability, and cyclical economy related to chocolate manufacturing. A complete analysis and description are presented in this paper.

## 1 Introduction

The continued use of non-renewable energy sources, such as fossil fuels, has drawn attention to the development of more sustainable practices. Sustainable development is defined as determining ways to meet the needs of the present without compromising future generations to meet their own needs (Brundtland, 1987). This definition has allowed all people to understand new ways to lead more sustainable lives. Sustainable development has been adopted by many corporations, from independent companies to governments (Giddings et al., 2004).

Engineers have developed tools to incorporate sustainability in the development and retrofit of processes. Sustainable development in engineering terms typically applies to ways to conserve natural resources, preserve the environment, and manage process waste effectively (Hesketh et al., 2004). In order to achieve sustainable development in engineering education as per the Barcelona Declaration, new teaching strategies and evaluation and assessment techniques must be incorporated (Engineering Education for Sustainable Development, 2004). One such increasingly prominent and effective method for evaluating environmental impacts is through the use of life cycle assessment (LCA). An LCA allows for a full "cradle-to-grave" analysis of the manufacture of a product. It incorporates the emissions and energy requirements of all raw materials, processing, transportation, use, and waste management. The use of LCA software further allows one to quantify environmental impacts.

Engineering curricula among credited engineering programs in the United States have shown a progression towards incorporating sustainable development education (Murphy et al., 2009). Over 80 % of highly rated universities include some level of sustainable engineering education (Murphy et al., 2009). Over 30 existing courses among curricula were found to promote some extent of sustainable engineering content in traditional engineering courses. Of the courses, varying levels of sustainable engineering content from below 10 % to over 50 % were identified. Almost 70 courses among curricula were identified as dedicated sustainable engineering courses. Among sustainable engineering courses in all disciplines, only about 50 % incorporate life cycle inventories (LCIs) (Murphy et al., 2009). Thus, there is an observable increase in sustainable development education among engineering programs, but a slower rate of LCA education in these courses. EarthShift® employee Doherty interviewed multiple professors of engineering programs to investigate the level that LCAs are incorporated into their curricula (Doherty, 2013). Professors' responses showed LCA methodology is introduced at the undergraduate level, but detailed analysis is not introduced until the graduate level. Recently, LCA education is becoming more of a requirement, rather than an elective, in sustainable engineering programs. A recent example of LCA education in an engineering curriculum by Farrell and Cavanagh has shown an effort to introduce the topic and analysis to first-year engineering students (Farrell et al., 2014). The project included the students creating biodiesel and conducting an LCA to compare the impact of its production to that of petroleum-based diesel. An assessment of the students showed an increase in conceptual understanding and knowledge of LCA by 55%.

The focus of this paper is to demonstrate the applications used for education of sustainable development to first-year engineering students. An important aspect of The Barcelona Declaration is the ability of today's engineers to be able to work in multidisciplinary teams to adapt current technology to meet demands imposed by sustainable lifestyles (Engineering Education for Sustainable Development, 2004). Students evaluated in this paper have worked in such teams to meet the goals of the course. The objectives of each of the laboratory exercises were developed with focus on sustainability and a main engineering concept and are discussed in the Experiments section.

The exercises were based on the incorporation of sustainable development in chocolate manufacturing. More specifically, students were focused on the process of making chocolate truffle products. Students looked at material and energy balances to assist in determining where waste was produced in the truffle production process. Chocolate manufacturing has a high appeal to most, and it is able to keep student interest high. The industry also has been linked to controversial social issues. It is widely reported that cocoa plantations rely on child labor, often slavery, to keep prices competitive (Nagle, 2008). Child slave labor has increased as production increases in Western and Central Africa to keep up with demand (LaFraniere, 2006). Recent efforts by the United States Department of Labor, the governments of Ghana and Côte d'Ivoire, and the International Chocolate and Cocoa Industry have attempted to reduce child slavery on these plantations (Harkin-Engel Protocol, 2010).

As an introductory engineering course, students developed core skills that can be useful in other aspects. Such skills include working in multidisciplinary teams and analysis and interpretation of data. Students developed skills in LCA by developing LCAs of their chocolate truffle products. This allowed students to understand the impact of their products and discuss methods for reducing it. This purpose of this paper is to describe the results of the how receptive the students were on sustainable development with regards to socially ethical and environmentally aware practices in chocolate manufacturing.

## 2 Experiments

Many of the experiments that will be described were previously described in the paper *An Edible Education in Sustainable Development: Investigating Chocolate Manufacturing in a Laboratory-Based Undergraduate Engineering Course*, by Struck-Jannini, et al. (Struck-Jannini, et al., 2015) For the completeness of this report, exercises that were unchanged are described again. Those that were updated or changed will be noted. The deliverables of the first three experiments were used as building blocks to a full laboratory report.

The first laboratory exercise involved the students conducting a literature research about the chocolate production and manufacturing and LCAs. Students were introduced to various library resources for finding credible sources and information. The second laboratory exercise of the semester was the first "wet" laboratory experiment. Students entered the food-safe laboratory wearing proper safety attire, according to good manufacturing practices (GMPs). Attire included: safety glasses, gloves, hair net, and beard net (if necessary). The experiment introduced students to practical applications of a mass balance and waste management by having them make their own truffle center product. The truffle centers were created using chocolate and heavy cream as raw materials. Students measured the mass of all equipment and raw materials before processing and the mass of the products and equipment after processing. The objective was to note that the mass of the raw materials and the products are not equal. They would identify steps to ensure control of raw material handling. In addition, the concept of the mass balance was used to determine the nutritional information of their truffle center products.

The third laboratory exercise had the students manually temper chocolate and introduced them to the energy balance. Tempering chocolate is the process of heating and cooling the chocolate to destroy undesirable fat crystals and recrystallize the desirable, more stable ones (Afoakwa, 2008). Such characteristics include a desirable sheen and snap and a higher melting point than chocolates composed of the undesirable fat crystals (Afoakwa, 2008). A watt-meter was used to record the amount of energy drawn from the hot plate. The energy balance was incorporated to calculate the amount of heat required to raise the temperature of the water and melt the chocolate. Students were to speculate how else the energy may have been transferred in the process. The fourth laboratory exercise introduced the students to a tempering machine (ChocoVision, 2011). The tempering machine automates the tempering process, thus reducing the possibility of overheating the chocolate. If the chocolate is overheated, the stable crystals will begin to melt and the process of reducing the chocolate temperature will need to be repeated. Students created a full truffle product consisting of the ganache center fully enrobed in chocolate tempered by the tempering machine. Students performed a statistical analysis on the truffle centers before and after enrobing. The students should have seen an increase in variation after enrobing. Students were to suggest possible reasons as to why this occurred. Students also measured and recorded the energy requirement of the tempering machine. The measurement was then compared to the energy requirement measured in experiment 3.

The fifth laboratory exercise had the students investigate possible empirical relationships of chocolate. Four chocolate samples of a range of cocoa percentages (33.4 % to 90 %) were analyzed. Student groups were given two chocolate samples and a mystery sample that was common with all groups. Students correlated melting point, absorbance, and taste to cocoa percentage in the chocolate. Students discussed which test they felt was most accurate and used their correlations to generate an estimate of the cocoa percentage of the mystery chocolate sample.

The sixth laboratory exercise introduced the students to LCA software. This laboratory exercise was done earlier in the semester with respect to the paper conducted by Struck-Jannini, et al. (Struck-Jannini, et al, 2015). It was updated to incorporate a more in-depth introduction to the LCA software, SimaPro®. By following the tutorial, students generated an LCA of their chocolate truffle product using the life cycle inventories (LCIs) of the raw materials. Students entered the energy requirement of their truffles as recorded in experiment 4. The students analyzed the LCA "tree" of their product to observe which materials had high $CO_2$ emissions and performed a damage assessment to observe where the products had a large environmental impact. Students altered their product to analyze two cases that would reduce the environmental impact of their truffle product. Those being a case with no material waste and one with energy requirements reduced by 20 %. The students compared the damage assessments of the cases to determine which had the least negative environmental impact. The seventh laboratory exercise had students investigate amounts of heated cream necessary to melt chocolate for truffle centers, in an attempt to cut down on the necessary amount of raw materials. However, this task needed to be completed without being detrimental to product quality. Students used chocolates of varying cocoa percentages and white chocolate to determine necessary amounts of heated cream to fully melt the chocolate for truffle centers. Students used the heat transfer equation to determine the energy required to melt the chocolate.

The eighth and final laboratory exercise of the semester had students create their own, original chocolate truffle product. Using the data recorded from previous experiments, students were to make a truffle product that had an acceptable quality and had a minimal impact on the environment. Students were responsible for recording the energy requirement of their truffles and determining nutritional information. Students were to generate an LCA of the truffle product. The final deliverable was to present their truffle product in a five minute sales pitch to a panel of instructors posing as possible investors. Students were to highlight the data from the process of creating their product, including the feasibility of scaling up and proper waste management. Students were also responsible for presenting LCA information and social awareness (i.e. responsible sources of raw materials) of their process.

## 3 Assessment

A two-part assessment instrument was developed to measure attitudes toward sustainability, social justice issues, and engineering knowledge related to the specified learning outcomes. The instrument was administered before the beginning of the project and at the end of the semester (pre- and post-test). The pre- and post-test were broken into two parts. The first part was an affective learning assessment that was used to determine changes in student's opinions. The second part was a cognitive assessment that was used to determine what the students learned. The pre-test had 105 students participate and the post-test had 109 students participate.

### *3.1 Affective Learning Assessment*

The affective learning questionnaire comprised of 14 items that focused on social justice and sustainability issues. Respondents indicated their level of agreement with the statement using a 5 point Likert scale with responses ranging from strongly disagree to strongly agree. Items were focused on the student's opinions on different social issues including questions about the chocolate industry. For this section, *Agree* represents responses that are "Agree" and "Strongly Agree" and *Disagree* represents responses of "Disagree" and "Strongly Disagree". A Likert Scale was used to analyze these results. This scale assigned values of 1-5 for question answers A-E with A being set to 1 and E set to 5. The overall score was calculated for each item, and a super overall was calculated by taking the sum of the Likert numbers and dividing it by the total amount of answers in that specific subgroup. Students' responses were compared between the pre- and post-tests to determine how their views towards different issues changed from the beginning. A positive change between mean pre- and post-test scores reflects a shift in attitude corresponding to increasing importance. Results of the Likert analysis of selected items from the pre-and post-test can be seen in Table 1.

The overall mean response for the pre-test was calculated to be 3.84, indicating an initial student response between "Neutral" and "Agree." The lowest mean response was 2.16 and the highest mean response was

4.56. For the post-test, the overall Likert response was 3.85. The low for a question was 2.29 and the high for a question was 4.60. The overall mean did not present a great change in attitude, so further exploration was conducted to identify which positive changes were balanced by negative changes.

The greatest increase occurred for Item 2, with an increase of 0.32 points. This increase may be attributed to the course focus on the impact of engineering decisions on people who do not have the information and voice to protect their way of life from large corporations. The largest decrease happened for Item 9 of the assessment. The decrease was 0.20. This decrease could be related to the final course deliverable. Students would be focused on the business aspect of the question compared to the social awareness aspect of the question. Another possible explanation of this trend is that the students valued the topic of other questions more than this question, making it less important in comparison.

The affective learning items were broken into scales based on the scope of the questions. Type 1 items were about the students' beliefs, type 2 items related to the importance of different factors in making engineering decisions for a company, type 3 items related to beliefs about the practices and policies that companies should have, and type 4 items related to personal behavior. How the items were broken down to each type can be found in Table 1.

Table 1: Item number, abbreviated item, Likert score, and scale for each item

| Item | Abbreviated Item | Pre-test | Post-test | Difference | Scale |
|---|---|---|---|---|---|
| 1 | I believe that matters of ethics are part of engineering practice | 4.26 | 4.26 | 0.00 | Type 1 |
| 2 | I believe that matters of social justice are part of engineering practice | 3.64 | 3.96 | 0.32 | Type 1 |
| 4 | When making engineering decisions, I would rate overall environmental impact as | 4.34 | 4.24 | -0.10 | Type 2 |
| 6 | When making engineering decisions, I would rate sustainability of the process as | 4.54 | 4.45 | -0.09 | Type 2 |
| 9 | When making engineering decisions, I would rate the impact on the local community as | 4.16 | 3.96 | -0.20 | Type 2 |
| 10 | I believe that the chocolate manufacturing companies should take measure to abolish child labor and trafficking from their material suppliers | 4.56 | 4.60 | 0.03 | Type 3 |
| 13 | I would be likely to purchase organic chocolate instead of non-organic chocolate for a 20 % higher cost | 2.59 | 2.82 | 0.24 | Type 4 |

When comparing the pre- and post-test mean scores for the four item scales, Types 1, 3, and 4 increased, while Type 2 decreased. The greatest increase occurred with the Type 1 questions which had an increase of 0.16. Based on the post-test results, all of the item scales were closer to agree. Item scales 1-3 were all above 4 which is between "agree" and "strongly agree", while Type 4 was just above 3 or "neutral". Figure 1 shows a graphical depiction of the results, with the complete results found in Table 2.

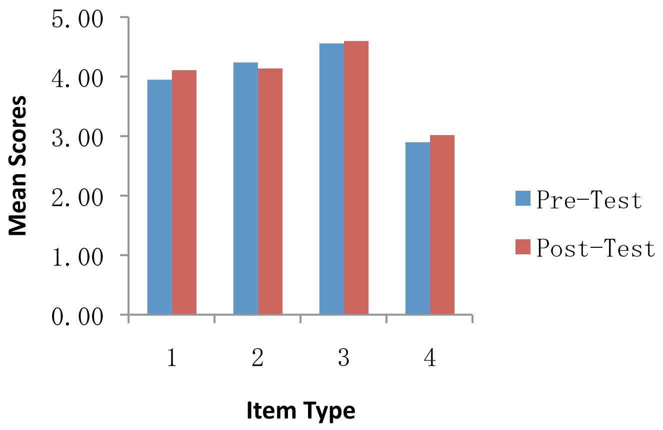


Figure 1: Pre-test and post-test comparison for each item type in the affective learning section of the instrument.

Table 2: Likert Scale Assessment for the Different Question Types

| Question Type | Pre-Test | Post-Test | Change |
|---|---|---|---|
| Type 1 | 3.95 | 4.11 | 0.16 |
| Type 2 | 4.24 | 4.14 | -0.10 |
| Type 3 | 4.56 | 4.60 | 0.04 |
| Type 4 | 2.90 | 3.02 | 0.12 |

When looking at how the individual Type 2 items changed, it was observed that all of the Likert scores decreased. This observation is possibly linked to more of a focus on the business aspect of the items compared to the social aspect. This is a similar observation to why Item 9 had the largest decrease. Another reason for this decrease is that the attitude of the students may have shifted from the importance placed on the area around them and became more of a focus on the communities that are immediately affected. These people include the consumers, employees, and the community around the facility.

### *3.2 Cognitive Assessment*

The cognitive assessment was used to evaluate if students achieved the learning objectives. The cognitive assessment consisted of 18 questions. Half were related to understanding LCA, part 1. The other half focused on the students' ability to solve problems, part 2. The overall score for the cognitive assessment increased from the pre-test, 64 %, to the post-test, 72 %. A paired two-tailed *t*-test was performed at the 95 % confidence level of 102 students. The difference was found to be significant. Sample questions and their type and score are shown in Table 3.

The lowest score for both the pre-test and the post-test was Question 14. The question went from having 13 % correct answers to 20 %. An explanation of the low score could be that the students did not have the correct equations to properly solve the problem. Another possible explanation could be that there was a lack of understanding in the difference between latent heat and sensible heat. Table 3 includes scores and the change in the scores from sample questions of the cognitive learning portion of the pre- and post-tests. The overall super score is in the last row of the table.

Table 3. Abbreviated cognitive questions including the pre- and post-test score and the question type

| Question | Abbreviated Question | Pre- | Post- | Score | Question |
|---|---|---|---|---|---|

| | | test | test | Change | type |
|---|---|---|---|---|---|
| 1 | The first step of Life Cycle Assessment is | 46 % | 47 % | 1 % | Part 1 |
| 4 | Choosing system boundaries for LCA may result in different environmental impact | 92 % | 97 % | 5 % | Part 1 |
| 7 | LCA commonly uses which basis of comparison | 99 % | 95 % | -4 % | Part 1 |
| 8 | Would you expect a smaller environmental impact from 1 kg of organic chocolate compared to 1 kg of non-organic chocolate | 51 % | 72 % | 21 % | Part 1 |
| 9 | Defining different system boundaries may result in a different social LCA result for social impact | 84 % | 94 % | 10 % | Part 1 |
| 11 | What are the possible sources of material waste in the truffle production above? | 40 % | 56 % | 16 % | Part 2 |
| 14 | 11.3 kg of chocolate is submerged in 40 kg of water. The chocolate is heated 25 °C while the water is kept at 80 °C. What is the latent heat required to melt the chocolate if the energy input is 267 Wh? | 13 % | 20 % | 7 % | Part 2 |
| 15 | In the question above, which quantity is the largest? | 33 % | 39 % | 6 % | Part 2 |
| 17 | If the process in question 16 is increased to produce 1 kg of chocolate, how much waste is produced? | 41 % | 39 % | -2 % | Part 2 |
| Overall Super Score | | 64 % | 72 % | 8 % | |

As mentioned previously, the questions were split into two separate parts, Part 1 which focused on LCA and Part 2 which focused on problem solving. When looking at the two parts, Part 1 had a higher score than Part 2. The change in both Part 1 and Part 2 of the cognitive results were found to be significant. A possible reason for the lower scores in Part 2 could be because the students were not exposed to those types of problems before the pre-test. The questions focus were on heat transfer, material balances, and energy balances, which is uncommon for first year engineering students to have experience with. The results from each part can be found in Table 4 and a graphical representation is illustrated in Figure 2.

Table 4: Results from each part of the cognitive assessment

| | Pre-Test | Post-Test |
|---|---|---|
| Overall | 64 % | 72 % |
| Part 1 | 79 % | 83 % |
| Part 2 | 49 % | 61 % |

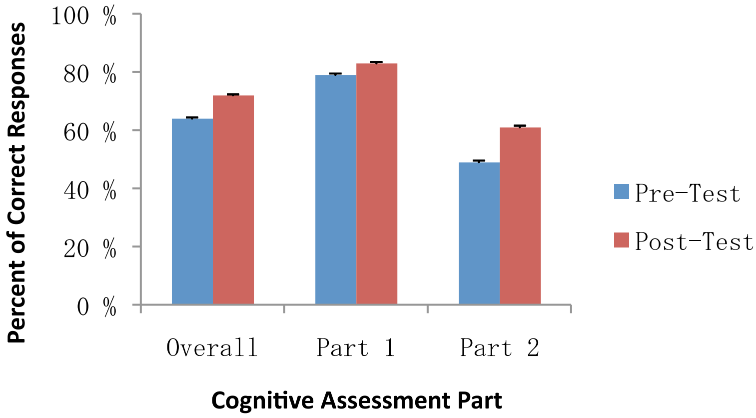


Figure 2: Graphical comparison of the overall super score, Part 1, and Part 2 of the cognitive assessment

## 4 Summary and Future Work

To develop students' knowledge on aspects of sustainable development with regard to socially and environmentally aware practices, eight laboratory exercises were created and incorporated in a first year engineering courrse curriculum. The exercises focused on sustainable development in the chocolate manufacturing industry, where social issues have become common. To determine the students understanding of the course material, a two part pre-test and post-test were given. The assessments focused on affective learning and cognitive learning. The affective learning portion focused on the social aspects of the course and measured how much students agreed with certain statements. Using a Likert-Scale analysis, the final mean score from the assessment was 3.85 which was an increase of 0.01 from the pre-test, which signifies a slight increase in social aspect awareness. The cognitive learning portion of the assessments focused on both LCA and the students' ability to solve problems. The final score for the cognitive portion was 72 % which was a significant increase of 8 %.

Future work for this test would be to further develop the laboratory experiments to increase the students learning. The course will also be adjusted to increase the Likert number by focusing on social aspects of running an engineering company which should improve the scores for the Type 2 items. More of a focus will also be put on teaching material and energy balances and heat transfer.

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# Training engineers to meet the challenges of a changing world: how a competency framework improves teaching programs and team cohesion

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**Abstract**

The competency framework is a complex and time-consuming exercise seen by most teachers as an administrative process. When applied, however, it can be a powerful tool for adapting curricula for engineers to meet the emerging needs of society, including training in sustainable development. This paper looks at how to use the competency framework to generate a tool for bringing teachers together around shared objectives, helping students build their career paths and improving communication with the 'outside world'. This approach, largely inspired by the Tardif approach, is being used for the Bioengineering Masters Degree in Environmental Sciences and Technology at the Gembloux Agro-Bio Tech Faculty, University of Liège, Belgium. The approach has allowed the teaching staff to build a common educational project aimed at enabling bioengineers to meet the needs of society.

## 1 Introduction

The 'Commission des Titres d'Ingénieurs' (CTI 2006) defines engineers as individuals who are capable of resolving technical, practical, often complex and, usually, new problems. Throughout their careers, these engineers have to design, create and implement products, systems or services that take into account environmental, societal and financial issues (CTI and AEQES 2013b).

The work of an engineer differs from that of a scientist, particularly in terms of implementing his or her scientific and technical knowledge. An analysis of our courses by the Commission des Titres d'Ingénieurs and the Agence pour l'Evaluation de la Qualité de l'Enseignement Supérieur (Belgian authority), however, showed that most of our teaching staff remain very focused on academic subjects (CTI and AEQES 2013a). It is important to train our students to apply their knowledge in real situations, and therefore our transmissive teaching methods need to be turned into 'learning-based' teaching methods.

It also seems clear that engineers and bioengineers should bear some responsibility for the sustainable development of our societies. This should be taken into account from the very start of their training.

This paper describes the establishment of the method in the Bioengineering Masters Degree in Environmental Sciences and Technology, which led to a revision of the existing curriculum, creating a new one that was consistent with the competency-based approach, was approved by the whole teaching staff and met the needs of the future employers of these students and society in general.

The definition of competency is still under discussion and there are currently several definitions. This work was based on the definition of competence as: 'a complex knowing how to act supported by the effective mobilization and combination of a variety of internal and external resources within a family of situations' (Tardif 2006).

This approach should ultimately enable us to generate a tool which will help:

- Relevant teaching staff to work around a shared objective
- Students to build their career paths by more effectively identifying the modules that will give them specific skills
- Improve communication with both the professional world and the 'outside world' (e.g., other universities, professional bodies, accreditation organizations)

## 2 Construction of the competency framework

The creation of a competency framework cannot emerge solely from academic world. It is our duty to prepare young and enthusiastic candidates to fulfil new responsibilities and lead the society towards sustainable functioning. Building a bioengineering course that meets the expectations of the professional world involves using this framework in this process (Colaux-Castillo et al. 2013).

In order to build a competency framework, we:

- Conducted a survey among employers and new graduates. It showed that, overall, our students' scientific and technical training was recognized as being of high quality. Some concepts, however, seemed to be obsolete. This was the case with the geometronic course, which focuses on meters, which is now an independent curriculum. This survey helped us to refine the profile of our future bioengineers and to identify the skills needed for new jobs.
- Analysed 210 employment opportunities for bioengineers. This showed variations in expected skills, emphasizing the importance of soft skills such as team management, communication and leadership (Figure 1).
- Looked at various competency frameworks ([EUR-ACE] 2008; CTI and AEQES 2013b; CTI 2006; OECD 2011).
- Analysed our bioengineering courses

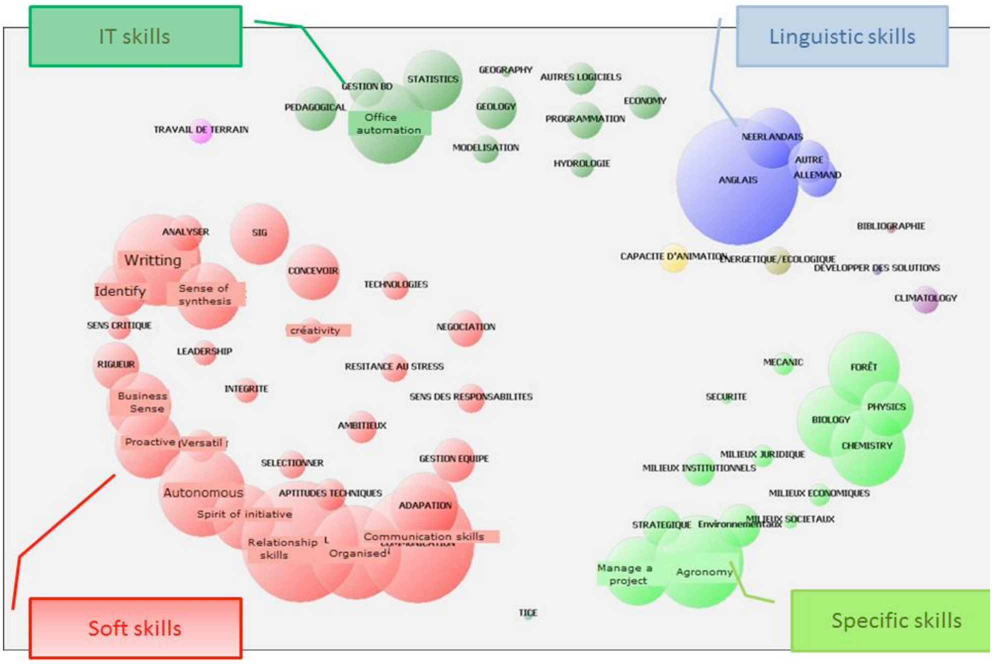


Figure 1: Lexical representation of the desired skills sought by employers

All these different sources of information allowed us to build a competency framework that was amended through iterative work. The draft framework was submitted to more than 219 employers. Their feedback (12%) was incorporated into the final version, which was based on skills (Figure 2) and was used as the starting point of the new teaching programme.


Figure 2: Final version of the competency framework for the Bioengineering Masters Degree in Environmental Sciences and Technology

## 3 Professional situations and Development trajectories

The competency framework is the keystone of the curriculum, but its constituent skills are general and complex (Tardif 2006). It is almost impossible for teachers to determine the learning activities directly from those general skills. In order to become more explicit, they were developed in real situations.

In order to help teachers integrate this guidance into course programmes, the skills are translated into professional situations. These professional situations take into account the extent and diversity of the area in which the said skill will be used (Tardif 2012). They describe what a student is able to do in the professional world when he is said to be 'competent' in those various skills. From these more clearly defined tasks, it is easier for teachers to determine the learning activities that will support students as they develop their skills.

For the skill described in Figure 2 as: 'Designing technological solutions for the equipment, systems, infrastructures and services that meet new or established environment-related needs', which is very general, we defined the following professional skill: 'Design, size tracking and production of equipment in the agro-environmental field', which is a contextualised skill, much more concrete and accessible not only to teaching staff but also to professionals.

Although the professional situations are clearer and more factual, they remain complex. They mobilise numerous resources, knowledge, abilities and attitudes. Developing a professional situation takes time and involves going through various stages of development. When children learn a language, they start by pronouncing a few isolated words before combining them into complex phrases. We learn to decipher words before we are able to read a book. These various stages constitute development trajectories. They involve progressively introducing complexity through the exercise of a skill. Development trajectories describe developmental processes and identify the levels to be achieved and the steps to be taken in moving towards professionalization (Tardif 2012).

In addition to the professional situation 'Design, size tracking and production of equipment in the agro-environmental field', we defined three levels of development: Novice, Beginner and Competent (Dreyfus & Dreyfus 1980; Hugonnet 2009). We expressed them entirely within the context of the professional situation (Figure 3). These different trajectories are connected to one another through the integration of increasing complexity in the path towards acquiring the full professional ability for this situation (Figure 3).

***Design, size tracking and production of equipment in the agro-environmental field***

| Level of Development | Development Trajectories |
|---|---|
| Novice | To ***measure*** physical and chemical parameters and variables in the environment in order to monitor it |
| Beginner | To ***design*** simple equipment ***on the basis of a specification note*** and using existing techniques |
| Competent | To ***quantify the performances*** of a system using an operational monitoring system |
| Competent | To ***develop*** a technological monitoring system in a complex environment |

Figure 3: Description of the development trajectories of a specific professional situation

Once these levels are clearly written, it becomes easier for teaching staff to identify the different courses and related learning activities that are involved in the training of those different development trajectories, but also the associated evaluations required to validate the acquisition of those levels.

**Professional situation :**

**Design, size tracking and production of equipment in the agro-environmental field**

Optional: Binary choice

| | | BA 1-3 | BA1-3 | BA1-3 | BA3 | BA3 | BA3 | MA1 | MA1 | MA1 | MA2 | MA2 | MA2 | MA2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Optional* | No | No | No | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes |
| | | Physics / Mathematics | Vegetal | Chemistry | Hydrology | Environmental Physics | Environmental Metrology | Pedogenesis and Soil Hydrodynamics | Field Applications & Visits | Rural Engineering | Automation | Precision Agriculture | Indoor Crop Production | Soil Atmosphere Gaz Exchanges |
| 1 | To measure physical and chemical parameters and variable in the environment in order to monitor it | | | | | EC | | | | | | | | |
| 2 | To design a simple equipment on the basis of a specification note and using existing techniques | | | | | | EC | | | | | | | |
| 3 | To quantify the performances of a system using an operational monitoring system | | | | | | | EC | | | | | | |
| 4 | To develop a technological monitoring system in a complex environment | | | | | | | | | | | | EC | |

Figure 4 :
Matrix development trajectories versus courses implied in the learning or the evaluation (EC) of those different development trajectories

The process of developing the matrix as set out in Figure 3 enabled us to shed light on certain inconsistencies in the existing programme. Some courses were poorly integrated into the trajectories and others appeared to contribute to several trajectories. This observation encouraged reflection and collaboration among the teaching staff. In some cases, courses were merged into modules that tackled the development of an entire level. In other cases, teachers reviewed their learning objectives in order to avoid a duplication of activities in the course. This led to discussions, exchanges and arguments, but ultimately the work strengthened the team spirit.

The development trajectories force each teacher to rethink the learning activities in terms of the acquisition of the described level of development. The activities are more integrated, more practical. Figure 5 illustrates an activity organised for the Pedogenesis and Soil Hydrodynamics course, in which students monitor water and solute flows through soil columns using various sensors as part of the learning related to the development trajectory: ‘To quantify the performances of a system using an operational monitoring system’.

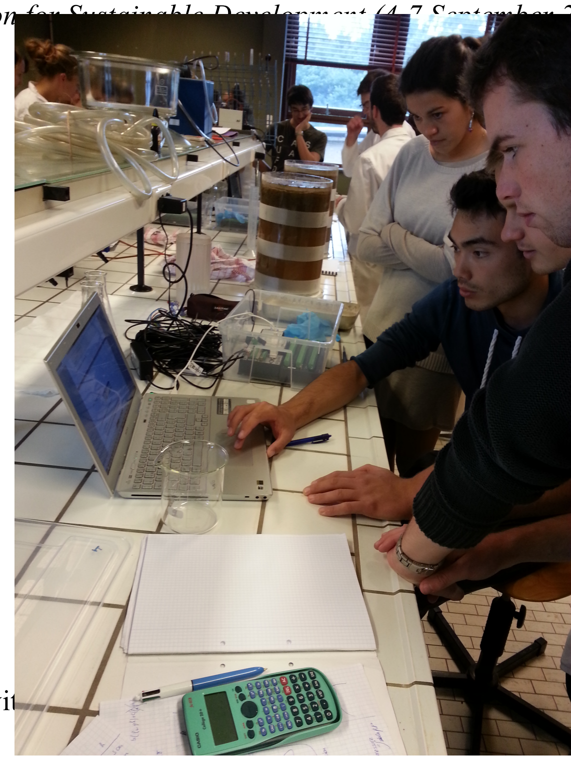

Figure 5: Learning activi… ory illustrated in Figure 3

The entire process leads to the coherent and optimal development of the course. Some teachers are in charge of the certifying evaluation, which tests whether the students have acquired the right level of skills. All these certifications are shared among the members of staff.

## 4 Impact of the competency framework on various actors

Building a competency framework is often seen as a complex and time-consuming exercise that remains abstract for most teaching staff and professionals involved in its construction. By integrating this guidance into the curricula through the professional situations, the framework can become a powerful tool that can be used by three categories of users: academic staff, students and professionals.

### *4.1 Collaboration and cohesion of the academic staff*

In contrast to past practice, where university professors designed their courses in a relatively independent way, this new type of teaching focuses on collaboration among teaching staff and transparency of content, with the shared objective of enabling students to master the skills required for their future career and for meeting the needs of society. Learning-based teaching requires teachers to concentrate on the acquisition of a developmental stage in the relevant professional situation. It induces better coherence in the curriculum.

This tool also helps to embed new teachers into a global project. There, they can identify the expectations of the team and the academic authorities with regard to their educational responsibilities.

This approach has provided an opportunity for our teachers to ask themselves how appropriate their course content is in terms of their teaching objectives. Better still, it has introduced new pedagogical content in response to new needs identified during the creation of the framework. A new dynamic has been established among those participating in developing this framework.

### *4.2 Tool to help students' choices of module*

For students, this tool will enable them to be more involved in their own education. It will be specially adapted to choosing the optional modules. Depending on their career choices, students can make more informed choices about the modules that will meet the skills levels of the trajectories they wish to follow. The tool will also enable them to know exactly what is expected of them at various points in terms of achieving the levels in question. Students therefore become actors in the process and take the steps required for them to be ready for the qualifying evaluations. They build their professional project in coherence with the learning activities offered in the curricula.

This tool is also used as an evaluation grid for taking in new students from foreign institutions in order to check the relevance of some academic mobility.

### *4.3 Communication with the professionals*

The use of the competency framework will enable the academic world to communicate more effectively with the professional world, setting out the tasks and levels of development that students should achieve in the various trajectories. Close collaboration with the 'Career Observatory' will ensure that learning responds as well as possible to the expectations of the professional world and to the new needs of society.

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# Sustainable development for ICT engineering students - "What's in it for me"?

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## Abstract

The importance of sustainable development (SD) is hardly possible to refute; however, sustainable development has been a relatively peripheral subject in computer-related engineering educations. Sustainability, with its global and potentially all-encompassing connotations, is still seen by many Information and Communication Technology (ICT) students as a topic of little relevance to their future careers. So how can teachers convince these students that sustainability is a topic that can be both relevant and interesting for them? From the point of view of the student; "What's in it for me?".

In this paper we describe and compare our efforts to plan and teach three introductory courses on SD in three different ICT-related educational programmes at KTH Royal Institute of Technology. The courses were planned separately, but they will be analysed together. We discuss two dimensions that we have found to be imperative in our endeavour to engage our students. The first dimension is to handle the balance between sustainability on a general level versus sustainability as specifically related to ICT. The second dimension is to handle the tension between teaching facts versus an emphasis on students' reflections and/or practicing skills. We argue that overcoming the challenge of making sustainability relevant to the students is central for successfully teaching these courses.

## 1 Introduction

The importance of sustainable development (SD) is hardly something that can be refuted in contemporary society. SD encompasses global and to some degree abstract issues such as planetary boundaries and human well-being (Raworth, 2012; Griggs, Stafford-Smith et al., 2013; Steffen, Richardson et al., 2015). Information and Communication Technologies (ICT) are one of the most influential instruments presently shaping our societies, and these technologies also harbour the potential for creating opportunities for sustainable development (GeSI, 2012; Becker, Chitchyan et al., 2015). Hence, it is imperative that the future ICT and computing professionals have a thorough understanding of SD.

However, from our students' point of view, these issues can be perceived as distant from their focus on computers and programming. For example, according to a 2015 questionnaire that was answered by all new students at KTH Royal Institute of Technology (from here on referred to as "the university" or "our university"), the three main reasons for students to apply to our three computer-related educational programmes were: 1) the reputation of the university, 2) career opportunities and 3) an interest in technology and the natural sciences. As to "contributing to a sustainable society", this option was chosen by a meagre 8% of the new Information and Communication Technology students, 6% of the Media Technology students and a dismal 2% of the Computer Science students. Our students imagine their future selves as busy writing code, designing apps or developing media content in their future professions, but not as working with anything related to sustainability. So, how can we get this particular group of engineering students to care about topics such as climate change, ecological crises, overpopulation, overconsumption, resource depletion, energy scarcity, global poverty, inequality etc.? From the point of view of a typical student, we as teachers need to be able to answer the question "What's in it for me?", as well as "Why should I care?" and "What can I do?".

In this paper we describe and compare our efforts to plan and teach three different mandatory introductory courses about SD to three different groups of ICT students at our university. The courses were separately, but we have all faced the same challenges of engaging these groups of students in sustainability issues. Moreover, in all three cases, the course in question constitutes a scant 6 or 7.5 credits out of five-year long, 300-credit educational programme. Furthermore, as these are stand-alone courses (rather than being part of an integrative (Mann, Smith et al., 2008) or transformative approach (Sterling, 2004) to SD), the issues that are raised in our courses might clash with other, dominant narratives within computing such as a belief in an almost law-bound ever-increasing availability of (progressively more inexpensive) computational power (e.g. Moore's law). The challenge for us, which will be discussed in this paper, is how to make sure these introductory courses are perceived as relevant and that they make a strong enough impact for the students to carry the knowledge and perspectives with them throughout the remainder of their education.

## 2 Background

In 2011, a central decision was made that each Master of Science in engineering (5 years, 300 ECTS credits) programme at our university should include at least a 7.5 credit course relating to sustainability, although the long-term goal is to better integrate sustainability into all parts of the educational programmes. Three of these programmes are related to Information and Communication Technology (ICT): Media Technology, Computer Science, and Information and Communication Technology. As is the case for all programmes at a technical university, after graduating our students usually end up working primarily in research- and technology-heavy industries and in consulting. For these three programmes in particular, this means traditional non-ICT industry companies, large ICT and telecom companies (e.g. Ericsson, IBM, Oracle) as well as a larger number of smaller (primarily) software companies. See table 1 for a short description of the programmes and their respective emphasis on curricula, student group, and job market.

In the Media Technology programme, at the school of Computer Science and Communication (CSC), the course Sustainability and Media Technology (DM2573) was developed by teachers connected to the program. It has been taught as a compulsory course for approximately 70 fourth-year students every year since 2012.

In the Computer Science programme, also at the CSC school, the course Sustainable Development for Computer Science and Engineering (AG1814) was developed by teachers at the school of Architecture and the Built Environment (ABE). The ABE School teaches a large number of sustainability-related courses and can be seen as "external sustainability experts" in this context. The course was given to first-year students the first two times (2013 and 2014), but has since then moved to the second year (2015), receiving approximately 180 students every year.

In the Information and Communication Technology programme, at the school of Information and Communication Technology, the course Sustainable Development, ICT and Innovation (AG1815) was also developed by teachers at the ABE school. Since 2013, it has been given twice as an elective and twice as a compulsory course. It has approximately 65 students every year.

Table 1: Information about the engineering programmes.

| Programme and school | Main subjects | Student group and job market |
|---|---|---|
| Media Technology@ School of Computer Science and Communication | The three largest subjects are mathematics, computer science and media-related subjects (all three are roughly equally large). | About 70 students per year. 48% female students in 2015.<br><br>After graduating, students end up working in traditional mass media and in new media industries. |
| Computer Science@ School of Computer Science and Communication | The two largest subjects are mathematics and computer science. | About 200 students per year. 14% female students in 2015.<br><br>After graduating, students end up working primarily as consultants, software developers and programmers. |
| Information and Communication Technology@ School of Information and Communication Technology | The three largest subjects are mathematics, computer science and finally electronics and computer technology. | About 80 students per year. 23% female students in 2015.<br><br>After graduating, students end up working primarily as project managers, software developers and programmers. |

Even though the three programmes have different foci, they have in common that sustainability has not been a major topic in the curriculum, and that it is oftentimes difficult for both students and teachers in the programmes to see how SD relates to ICT and computing. While SD is well integrated into several educational programmes at our university, the topic is seen as less relevant in other programmes, and it has to be said that the ICT-related programmes belong to the latter category. At the same time, ICT is a strong force in reshaping and transforming our society, and most of our students will end up doing exactly that to a smaller or a larger extent, and, this transformation needs to be sustainable. For example, when alumni were polled and asked about their employment and work tasks 2-4 years after graduation, about 50% of all students from these three programmes stated that their current job involved making assessments of aspects relating to sustainable development.

## 3 Method

As university-level teachers, we are used to reflect on the courses we give on a regular basis. Course evaluations from students help us rethink, reshape and develop our courses incrementally. In this paper, we have gone one step further. As part of the process of writing this paper, we met regularly to discuss and compare similarities and differences between our courses and between our experiences of teaching sustainability to ICT and computing students. Through these discussions we honed in on two dimensions that we found to be particularly important in our endeavour to engage our students:

- How to handle the balance between sustainability on a general level versus sustainability as specifically related to ICT.
- How to handle the tension between teaching facts versus an emphasis on students' reflections and/or practicing skills.

Measuring student engagement or the extent to which implemented measures have led to the effect intended is obviously a methodological challenge. For the purposes of this paper, we have used two sets of indicators to gauge student engagement: 1) student feedback through course evaluations and 2) student-initiated extra- or post-curricular activities related to sustainability.

## 4 Results and Analysis

In the following, we elaborate on the two dimensions of engaging our students, and describe how our courses were designed to address those.

### *4.1 General or specific sustainability perspective?*

Sustainability is clearly linked to a global perspective as it concerns issues such as planetary boundaries, climate change and societal development. Knowledge about sustainability on a general level is consequently needed, to impress the students of its importance, and to show the overarching connections between problems and solutions as well as to introduce systems thinking (Easterbrook, 2014). However, if we were to teach "generic sustainability", we would be in danger of losing the interest of our students, as they tend to focus on technology, programming apps and finding solutions to specific problems. Hence, we also need to become specific and to show our students how sustainability can be connected to their specific skills and interests.

In DM2573 (Media Technology), we had at first outsourced the first, smaller part of the course to teachers who were experts in environmental issues and sustainability but who did not succeed to sufficiently connect these topics to computing. The students were very critical and while we outsourced this part of the course once more, we switched to another "supplier". We have since the second year used a modified version of the game GaSuCo (Pargman, Hedin et al., Forthcoming), with partly customized questions related to media technology and accompanied by "insourced" lectures on general sustainability issues (Eriksson & Pargman, 2014). The ratio between general issues and ICT-specific sustainability issues is in the range of 40/60.

In AG1814 (Computer Science), the program coordinator specifically required for the 2015 round, that the course should clearly connect to the students' ICT skills and their future job market and that the course should also have a stronger focus on social sustainability and ethics. A significant share of the course content is clearly connected to software development and to ICT in general. At present, the course consists of a lecture/seminar series corresponding to 3.5 credits and a project module corresponding to 2.5 credits. Only one out of six lectures and two out of four seminars treat more general SD content. The remaining lectures and seminars are specifically focusing on positive and negative impacts of ICT.

In AG1815 (Information and Communication Technology), an explicit request from the program coordinator was that the course should clearly connect SD to the students' ICT skills, future job market, and to ICT innovations. The course therefore has a very limited amount of general SD content. The major part of the course consists of lectures, a group project, and an individual literature assignment, all addressing SD challenges in different industries or societal sectors where ICT is currently being used, or could potentially be used, for solving SD problems and for contributing to new products and markets.

## *4.2 Focus on facts versus reflection/practicing of skills?*

Teaching at a technical university, an emphasis on objective facts and measurable data are at the heart of education. However, in our analyses of the courses, we have all tried to handle the tension between on the one hand facts (that for the students can turn into surface learning strategies and cramming for exams (Biggs, 2011) and on the other hand reflections on values as well as learning practical skills. While sustainability undeniably involves facts about climate change, biodiversity loss and health in developing countries, it is as a subject simultaneously deeply value laden and pathways to more sustainable societies are inherently normative as well as crypto-political (Baker, 2006), We have tackled this tension with slightly different strategies in our respective courses. In DM2573 we have counterbalanced facts with mainly reflections, while in AG1814 and AG1815 we have focused more on integrating SD into the practicing of skills as a counterweight to a unilateral emphasis on facts.

In DM2573 (Media Technology) the focus on reflection and values is primarily connected to a series of seminars where students have to read texts and reflect on a new theme each week. Each student also contributes to the seminars by formulating and submitting a topical question ahead of each upcoming seminar. The question represents a topic that the student suggests we should discuss at the seminar, and the teachers then chose seminar questions from the list of students' suggestions. Furthermore, students are also asked to submit more personal reflections through home exam questions each week.

In AG1814 (Computer Science), the students are encouraged to reflect on SD goals and values, and the role of ICT and computer science in contributing to those goals/values, mainly through a written self-reflection assignment as part of the project work. The project work consists of developing a prototype and it requires students to synthesize from both general and more field-specific SD knowledge to develop a prototype with the potential of having a high impact in terms of sustainability. This includes considering the problem addressed, materials used, reflecting on the potential uses and misuses of the product as well as global, rebound and other effects.

In AG1815 (Information and Communication Technology), the practice of ICT skills in connection to SD is realized in a group project, constituting around half of the course workload. The project assignments are formulated by companies and research institutes that are either currently active in developing ICT solutions to SD problems or that are interested in exploring such opportunities. A large variety of project assignments have been used in the course but what binds them together is their reliance on students' ICT skills. This approach provides a natural connection to their education but there is also a risk that problem solving and developing ICT solutions happens at the expense of dwelling on SD aspects of the problem.

## *4.3 Student engagement - indicators of success*

In DM2573 (Media Technology), questionnaires have been sent out before, during, and after the course. The replies show that students' relationships to sustainability change during the course; shifting from being indifferent or concerned to becoming more concerned but also towards acting upon that concern. In the final evaluation, the students are generally very positive about the course, as exemplified in the following quote: "Very relevant course and I have enjoyed it. I do however think that the media technology/ICT aspect could have been a bit more central in the course." The quote also shows that despite having worked hard to connect sustainability to other topics in the educational programme, there is still more to do.

In AG1814 (Computer Science), a questionnaire was sent out after the last lecture in the 2015 course. When asked about "stimulating tasks", 64% of the students answered that they were working with important and interesting tasks and that it was encouraging to work with a specific purpose or goal of the society. "I think this is an important course, and I will always remember what we learnt". However, only 12.4 % of the students answered that the course was challenging in a stimulating way. Maybe it is too early to teach this course in the second year since the students don't have enough knowledge in computer science yet. The students particularly liked the seminars: "I liked the arrangement with seminar assignments and how they were linked to the home exam". "The seminars were a very good opportunity for discussion and everyone had something to say/contribute to the discussion".

In AG1815 (Information and Communication Technology), when asked about the students' sense of "meaningfulness" of the course, about 80% agreed that "I worked with interesting issues" and "I could learn by trying out my own ideas". Students were generally positive about the group project and rated the contacts with industry as stimulating and as good way to practice SD knowledge in relation to ICT skills. Still, only about 50% agreed with the statement "The course was challenging in a stimulating way". It might be that the course contents are not advanced enough and a certain level of ambiguity of having to study SD as an ICT student can also be read into the comment "It's needed, although I don't enjoy it very much. It's good to be introduced to sustainability, regardless of what you study".

### *4.4 Other examples of extra- and post-curricular activities*

In DM2573 (Media Technology), students last year (2015) asked for the seminars to continue also after the course ended. This resulted in regular student-led lunch seminars where different aspects of sustainability were discussed throughout the rest of the semester. There has also been a significant increase in interest to write both bachelors' and masters' theses about sustainability-related topics from both DM2573 and AG1815 students.

Older students often become engaged as teaching assistants in software programming courses. This has been tried once in one of our courses when a student from AG1815 worked as teaching assistant in AG1814. We see this as an excellent way for older students to act as role models for younger students and this may hopefully contribute to engaging the students in the topic. Furthermore, a possible sign of long-term impact of these SD courses would be when students end up working with problems relating to SD in the ICT sector. One examples of this is a student from DM2573 being part of a green energy start-up company, Greenely[1]. Another example is a former student returning to AG1815 after graduation to supervise course projects, but this time representing her new employer.

## 5 Discussion

We have elaborated here on how we, in three introductory courses, have met the challenge of engaging students studying ICT and computing in the topic of sustainability. We have in particular focused on two different dimensions; 1) how to handle the balance between sustainability on a general level versus sustainability as specifically related to ICT and 2) how to handle the tension between teaching facts versus an emphasis on students' reflections and/or practicing of skills. There are several other tensions that arise in sustainability education (Pargman & Eriksson, 2013), but we have found these two the most interesting to explore in unison.

[1] https://greenely.com/

We stress the necessity of meeting the students where they are, emphasising the connection between ICT and sustainability. Something to be aware of is however that this emphasis could potentially dilute the importance of sustainability in its own right, if the learning activities and lectures become more inspirational than connected to larger sustainability concerns. We also hasten to add, that even if we have highlighted meeting the students where they are, it is equally important to prepare the students for their future professions, for example linking sustainability to system development project processes.

There are also some significant differences that could be mentioned when comparing these three courses. As teachers, we have different (disciplinary) backgrounds. Three authors have a background in computing and have moved towards sustainability, while the other two authors have a background in environmental and sustainability fields and have moved in the other direction. Working with the paper, we have noted an interesting element of “overcompensation”; some authors with a background in computing have felt the need to read up on and emphasise sustainability, while another author with a background in environmental strategies instead have felt the need to put in effort to display her “street cred” when it comes to IT development (showing that she understands key concepts and can use industry acronyms competently). This has led to the course given by the computing teachers (DM2573) has a stronger emphasis on the importance of sustainability in general than the other two courses.

Finally, it is possible to raise the discussion to a more general level, and ask what the mission and goal of these courses are. Here, a minimal goal is to formally fulfil the degree objectives for engineering educations that are established in the Swedish Higher Education Ordinance. However, we as teachers are invested in sustainability and believe there is more to the subject than the relatively general formulations of the Ordinance. We have all strived to make sustainability relevant, and to make our courses meaningful and engaging for these particular groups of students, i.e. we have gone into clinch with the question in the title of the paper: if students (justifiably) wonder “what’s in it for me?”, we all strive to make it relevant for them in our respective courses.

However, it is possible to aim yet higher, and the next level would be to strive for “impact”. Taking into account that our courses constitute only 7.5 credits in 300-credits (five year long) engineering programmes, can we aim for having an impact above and beyond the small “footprint” of our courses in the larger curricula? How can we encourage students to carry questions related to sustainability with them to the other courses they study (for example querying or challenging other teachers), to their thesis projects, to their work life and perhaps into their personal lives? Furthermore, yet a higher aim would be to educate and encourage students to themselves become sustainable “change agents” in the various contexts that they will later encounter (both in working life and in their private lives). This is however a high, and perhaps not fully realistic goal, to reach for in just one short course. A more practical goal in the here-and-now then, could be to strive to influence other teachers to incorporate issues relating to sustainability into their courses (for example by making connections to the UN SDGs) and working towards better integrating sustainability into the educational programmes - rather than only setting aside one single course “where everything should happen”.

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# Integration of ecodesign in engineering programmes through the application of the Ecodesign in Higher Education kit (EHE kit)

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## Abstract

The economic and ecological problems in our society compel the government, companies and consumers to take specific steps towards a circular economy. Designing products that are sustainable through their entire life cycle - or applying the principles of ecodesign - is a must to make this transition. Anchoring ecodesign as a sub-discipline of sustainable design within educational engineering programmes can thereby support a greater uptake of the circular economy in the business world. This article presents insights from the application of the Ecodesign in Higher Education kit (EHE kit) in higher engineering education in Belgium. The toolkit provides a hands-on guide and an integration model to educational staff, professors, education coordinators and education councils for integrating ecodesign into higher education programmes. The Public Waste Agency of Flanders (OVAM) owns and disseminates the toolkit. As part of the dissemination, OVAM has up to now organized 19 interactive working sessions with actors of 17 different higher education programmes in Flanders, Belgium. The participants work together on the analysis of the existing curriculum and the search for opportunities to improve the integration of ecodesign. The results of the organized working sessions indicate that the framework, methodology and roadmap provided in the toolkit offer welcome support to integrate ecodesign within the curriculum of engineering educational programmes in higher education, as it takes effort from various actors and on different levels. Moreover, the application of the toolkit gives indications on the need for a change in our educational thinking when it concerns the integration of ecodesign in higher education: it is not enough to add an additional course to the curricula. These and other promising findings on the application of the EHE kit in practice, and how this can support a shift towards a circular economy, are presented and further discussed in the article.

## 1 Introduction

The students of today are the professionals of tomorrow. They obtain values, standards, skills and knowledge through their education, among others. Higher education graduates end up in careers and functions where decisions are taken at many levels. Education, and certainly higher education, is thereby important for ensuring a sustainable society in the near and far future. A growing group of higher education institutes recognize that integrating sustainability into academic curricula is essential for providing students with the skills and insights to help societies become more sustainable (Lozano, 2010). The economic and ecological problems in our society compel the government, companies and consumers to take specific steps towards a circular economy. Designing products that are sustainable through their entire life cycle - or ecodesign - is a must to make this transition. Engineers often take decisions within the design and production process, as well as on the value chain of environmentally sustainable products and services. This is strengthened by Thomas et al. (2013), who state that many disciplines within the industrial sector are occupied by graduates with an engineering degree. Ashford (2004) emphasises the importance of focussing on engineering *'because the activities that drive the industrial state are generally rooted in engineering'*. Anchoring ecodesign as a sub-discipline of sustainable design within educational engineering programmes can thereby support a greater uptake of the circular economy in the business world. The Ecodesign in Higher Education toolkit - or EHE kit - provides a hands-on guide and an integration model for educational staff, professors, education coordinators and education councils that supports the integration of ecodesign into higher education programmes (Verhulst and Van Doorsselaer, 2015). The Public Waste Agency of Flanders (OVAM) owns and disseminates the toolkit. This article offers insights on and from the application of the EHE kit in higher engineering education in Flanders, Belgium. After a short introduction on the toolkit the dissemination process and methods for application are described. Following that, the article presents the results from the application of the EHE kit in different engineering programmes in higher education in Flanders and discusses findings and future directions.

## 2 The Ecodesign in Higher Education toolkit

The goal of the EHE kit is '*to support teaching staff in integrating ecodesign in the curriculum of higher engineering education'*. The toolkit aims at doing this through informing, motivating and inspiring teaching staff, whilst simultaneously raising awareness and connecting individuals with each other (Verhulst and Van Doorsselaer, 2015). The EHE kit consists of a guide, cards and worksheets.

1. The **guide** provides background information about a stepwise approach for integrating ecodesign into a higher education programme. It is recommended to read the guide as a way to getting started with the EHE kit.

2. Three types of **cards** contain specific and concise information on ecodesign learning content, teaching methods and practical examples. The cards have a workable format: each card type has its own color, thereby raising the user-friendliness of the toolkit: I) **Learning content cards** describe the various relevant themes connected to ecodesign. Each card gives a short description of the theme, the most relevant references about this theme and a link to practical example cards that present a case where the ecodesign theme is applied in practice. II) **Teaching method cards** describe activating teaching methods that get applied when integrating ecodesign in a course of the educational programme. Each card gives a short description of the teaching method, provides references to a more extensive explanation of the method and a link to practical examples in which this method is applied in practice. III) **Practical example cards** provide examples from practice with specific learning content and teaching methods. They can serve as inspiration for applying ecodesign in one's own educational programme. Each card describes the example, the applied learning content, which competences are developed, the applied teaching method(s), possible points of attention and a reference to the educational programme where the example is used.

3. **Worksheets** make it possible for educational staff to get started on their own. There is a work matrix and a blank example card: I) The **work matrix** has pre-defined rows, which represent the various ecodesign themes (learning content). The team that works on integrating ecodesign into the curriculum can complete the columns with the various courses from the curriculum and how ecodesign is currently already part of these courses. Next to that, proposals can be made on how ecodesign can get further integrated within and across different courses in the educational programme. II) A **blank example card** offers a basic structure to the educational programme supervisor or lecturer and helps them to make a connection between a certain course, an ecodesign theme and a certain teaching method.

A more detailed description of the development of and concept behind the toolkit can be found in the article *'Development of a hands-on toolkit to support integration of ecodesign in engineering programmes'* by Verhulst and Van Doorsselaer (2015). Next to that, the complete EHE kit - the guide, the cards and the worksheets - is freely available at http://www.ecodesignlink.be/en/tools.

## 3 Dissemination process and methods for application

During the developing process of the toolkit, the draft version of the EHE kit has been tested by the target group. Participants of this verification working session included teaching staff, educational programme coordinators and sustainability coordinators from ten different engineering programmes in Flanders (Verhulst and Van Doorsselaer, 2015). Following the finalization of the EHE kit, OVAM organized a 'teach the teacher programme' at 3 design engineering education programmes in Flanders. This was set up as three separate working sessions with the toolkit that served as pilot cases. Insights from these sessions were gathered and have supported OVAM to further develop a dissemination strategy. Next to that, it provided input for refining the methods for applying the toolkit in practice. In the years 2013-2014, working sessions were organized for 8 electromechanical engineering education programmes in Flanders. The following year, OVAM aimed at a larger target group of engineering education programmes. The subsequent steps of the dissemination process are explained in the following sections.

**Step 1: contact with the educational programmes.** OVAM made an overview of all relevant educational programmes. The head of each of the different relevant educational programmes received an introductory email with information on the EHE kit and the offer of OVAM to organize a working session with the toolkit in their educational programme. Existing contacts from OVAM in higher education – i.e. lecturers - received a similar email. Next to that, each head of the educational programmes in the inventory also received an EHE kit by post. Following this initial contact, OVAM contacted all different heads of the listed educational programmes by telephone to check their interest in a working session with the EHE kit based on the information received, and simultaneously to remind them of the offer and to encourage them to join a working session with their educational programme. This personal contact by phone turned out to be a very important, but time-consuming activity.

**Step 2: working session with the head and educational staff of the programme.** Once an educational programme decides that they wanted to do a working session with the EHE kit, a date and time got proposed by OVAM for a session of 2 to 3 hours. Every participant is given his/her own EHE kit. After an introduction on ecodesign and on the EHE kit, educational staff of the educational programme work with the toolkit, and more specifically with the matrix – the worksheet within the toolkit. The cards (learning content, teaching method and practical examples) are used to inspire the participants. The matrix gives an overview of learning content related to ecodesign and sustainable development. The team of educational staff fills in the matrix with courses of the own curriculum and the teaching methods that are being used. They thereby search for links with the learning content. This way the matrix shows the situation as is and indicates opportunities to (further) integrate ecodesign and sustainable development in the curriculum in the future. At the end of the working session, participants were asked for their feedback on the use of the toolkit, the results and on the working session.

**Step 3: selection of learning content.** The completed matrix gives an overview of learning content related to ecodesign or sustainable development that can be focused on more in certain courses of the curriculum. Mostly these are courses of educational staff that participated at the working session. Sometimes the lecturer of a course that was discussed in the working session could not be present. The colleagues that were present or came up with opportunities for integrating ecodesign in that specific course will then have to convince their colleague - the lecturer - to adapt the course. It is the responsibility of the educational staff to make the courses more sustainable! OVAM was not involved in this step.

**Step 4: integrate ecodesign or sustainability in the curriculum.** The matrix that got completed during each of the working sessions indicates which changes can support the curriculum to become more sustainable. Courses can for example be switched over different years of the programme in order to spread ecodesign themes more evenly through the curriculum, or learning content of one or more specific courses can be adapted. It turned out that in most of the cases, a majority of the teaching staff was present at the working session, which made it possible to proceed working together with colleagues on changing the curriculum after finalizing the working session. However, indications were given that taking the integration of ecodesign in the curriculum a step further also strongly depends on several external factors, such as recent changes in the curriculum, the presence of a sustainable mission and vision of the university or university college, who the decision maker is, the presence of a sustainable vision of the head of the educational programme, etc. The progress towards this next step of integration of ecodesign in the educational programme is thus also strongly dependent on the motivation, situation and other factors being present within the education programme, and OVAM has no or limited impact on it.

**Step 5: follow-up by OVAM.** OVAM has organized initial working sessions for several educational programmes with the aim to give each of them an overview of their current situation on how ecodesign is already present in the educational programme, and to think about and discuss opportunities for further integrating ecodesign and sustainability. However, as mentioned earlier, it is the responsibility of the university or university college to further work with the integration of ecodesign in their educational programme by making real changes in their curricula happen. In order to get an overview of what has happened after completing a whole range of working sessions at different educational programmes, OVAM contacted (through email) the head of the educational programmes that joined a working session at the end of the academic year to check if further action was taken in which the results of the working session was used. All participants of the working sessions receive the same email.

## 4 Results from applying the EHE-kit in engineering education in Belgium

19 working sessions have been organized for 17 different educational programmes in higher education in Flanders. In these sessions, 8 -out of 12- electromechanical engineering programmes in Flanders searched for opportunities for (further) integrating ecodesign in their curriculum. In total, 66 educational staff participated in the process. On a yearly basis, 500 students graduate from these 8 programmes. Next to that, more than 120 educational staff participated from other educational programmes in industrial science and engineering, including electronics & engineering, chemical & biochemical engineering, construction, energy, nuclear technology, packaging technology, agriculture, food technology, and textile technology. More than 800 students graduate yearly from these educational programmes. The following sections discuss insights on the application of the EHE kit in working sessions, based on insights from the working sessions' leaders, from direct feedback provided by the participants, and based on follow-up activities after participation of an educational programme in a working session.

### *4.1 Insights from working session leaders (provided by OVAM)*

Disseminating something new to a specific target group is always a craving job. This also turned out to be the case with the EHE kit. Contacting all relevant educational programmes takes a big effort. One issue that came forward is that the head of an educational programme usually also has teaching as one of their work tasks. A result of this is that they are often very busy and difficult to reach. Throughout the first step in the dissemination process, OVAM changed its approach and decided to focus on directly contacting those people that replied to the initial email and showed interested in the proposed working sessions. Another insight that came forward during several of the working sessions is that it turned out difficult to convince educational staff of changing their course, teaching method or learning content. Next to that, the input in the working sessions showed that courses and curricula are in a majority of the cases already packed, whereby the teaching staff feel there is no room left for additional topics such as ecodesign or sustainability. Working with the matrix however showed several opportunities to relate the existing courses to sustainability topics, without needing extra time or space in the course or curriculum.

### *4.2 Insights from direct feedback of participants after working sessions*

In short, the feedback of the participants on the EHE kit was always very positive. Feedback received on the use of the EHE kit emphasised that the toolkit is a good instrument to work with, e.g. *it speaks the language of educational staff, lecturers are used to thinking about learning content and teaching methods, the matrix is very hands-on, the cards are very inspirational*. Participants also indicated that the working sessions were very useful for them. One of the main aspects on which feedback was given relates to a more profound understanding of the curriculum and the different courses within. Educational staff of the same programme usually knows from each other which courses they give, but they often do not know the learning content of those other courses. By bringing them together in the working session, they could learn from each other, discuss useful learning content and the composition of the curriculum in a constructive and fun manner. Another issue that came forward from the feedback from participants - often given immediately after finishing the working session - is that they found it very satisfactory to realise that there is always a way to relate a course to learning content on ecodesign or sustainable development. Opportunities for ecodesign were for example found in courses on climate control, materials, design, automation, energy technology, sustainable engineering, and innovation management, but also in more general courses like statistics, mathematics or philosophy. The toolkit and its application thereby serve as an eye-opener to the participants on possibilities to work on ecodesign they did not consider before. Next to that, also bachelor or master theses and small business projects were indicated to offer many opportunities for students to focus on sustainability issues. Sometimes the participating educational staff is surprised to realise that they already focus on one or more of the topics related to ecodesign and sustainability, but approach it from an economic perspective, without taking into account the ecological impact, e.g. energy saving of machines. A last issue on which feedback was given by participating educational staff shows that they find it important to have relevant information such as exercises and examples available on the topics discussed. Working multidisciplinary was thereby indicated as a big advantage, e.g. by not only focusing on themes relevant for engineering programmes but also including relevant themes for economic and other degrees. A complementary initiative that focuses on providing information for economic degrees has been completed by LNE – Ecocampus with the EDGE-kit[1]. In order to meet this need and request for multidisciplinary information, OVAM has investigated how relevant information for educational staff can be provided on the broader topic of circular economy[2]. Next to that, OVAM also organizes working sessions that target students with OVAM tools such as the Ecolizer and OVAM SIS Toolkit[3].

### *4.3 Insights from follow-up at educational programmes*

Who the decision makers are on the level of an educational programme can vary strongly within different universities and university colleges. It can be the head of department, educational management teams, a departmental working group, etc., that can decide about what and when to change in the curricula. The impact educational staff has on providing change in the curriculum is thus strongly dependent on how power is divided within the educational programmme. After joining the working sessions with the EHE kit, several educational programmes have adapted their curricula; for example two educational programmes in electromechanical engineering and another one in textile technology. These tree programmes indicated that working with the EHE kit motivated and inspired them. An interesting observation is that these are educational programmes where the teaching staff has influence in the development of the curriculum, and where the head of department participated at the working session. The changes made in the curriculum in these educational programmes have led to integrating sustainability as a recurrent topic within and throughout several courses in the curriculum, rather than adding a separate course on 'sustainability'. However, a larger number of educational programmes did not make any changes in the curriculum (yet) following on the completion of the working session with the EHE kit. Although no further progress has been made, those educational programmes still clearly indicate that the working session has been very useful to them: it made them think and reflect about ecodesign as a specific topic of sustainable development and it has motivated several educators to start working or work further on integrating sustainability in their own and other courses. An important point of attention is that it takes time to rethink a curriculum, and by providing the EHE kit, a method is available that can support this process.

[1] EDGE-kit: http://edgekit.be/
[2] http://www.pearltrees.com/t/circulaire-materialenbeheer/principes-circulaire-economie/id15223957#l531
[3] http://www.ecodesignlink.be/en/tools

In many cases, the participating educational staff realizes that completing the matrix within the EHE kit is preferably not a one-time event. A working session under the guidance of OVAM might not be necessary for a second session with the EHE kit, but it could be helpful to have a team of educators that regularly takes the time to examine and further develop the curriculum. Indications were however given that a trigger is needed for educators to do so. Another indication was given by several of the educators that they consider case based education as a driver for further integrating ecodesign in the curriculum. Working multidisciplinary was thereby indicated to be preferable. In order to support this, OVAM could for example take the role as facilitator and bring together different education programmes, which is something they already aim for with their OVAM SIS Toolkit working sessions. Several educators also mentioned to be convinced that the integration of ecodesign would become more common if curricula would be discussed with business leaders with the aim to fine-tune them with the needs of companies. Sometimes educational staff has a business activity next to being an educator. Indications were given that such lecturers more often see advantages of managing a company more sustainably and understand the importance of integrating sustainability in higher education programmes.

## 5 Discussion

### *5.1 Strengths*

Nowadays sustainability is an evaluation criterion for educational supervisors and councils. As a result of this, many educational programmes have been working on integrating sustainability in their mission and vision and were rethinking their curricula on the moment OVAM offered a working session with a hands-on tool. The authors believe that this has supported the success of applying the EHE kit in educational programmes in Flanders. Organizing a (free) working session under the guidance of external experts on the EHE kit and the topic of ecodesign thereby showed to be a strength in order to convince the head of department to work further on integrating ecodesign in the curriculum. Another strength of the toolkit is that educators at engineering programmes find the suggested learning contents and teaching methods very relevant. The topics that are described in the learning content cards make ecodesign tangible for educational staff, instead of a broad, abstract understanding of sustainability. Next to that, the working session results indicate that the method for applying the EHE kit is very adequate for educational staff to work with. The completed matrix thereby turns out to be a good starting point for the educational programme to continue the work.

### *5.2 Weaknesses*

There is still need for raising awareness about ecodesign and sustainability. A lot of educational staff is still not convinced about the need and importance to integrate these themes in higher education. Universities and university colleges are free to decide about the content of their curricula. It would be a big step forward when integration of sustainability becomes mandatory. Next to that, universities and university colleges are skeptical about sharing information on their curricula. This results from a competitive environment that is present in the Flemish educational arena. This makes that some lecturers are not eager to share or exchange experiences and learning content, which lies in the core of using the EHE kit and makes its application difficult. Another weakness of the EHE kit is its current focus on product related rather than process related topics. These could be more relevant for chemical or biochemical engineering education, amongst others. Also educational staff indicated to miss the social aspect of sustainability, such as communication, social marketing, behavior, psychology. For some educational programmes, it was suggested to also include economic topics such as business modeling, circular economy, as they are currently missing in the EHE kit.

### *5.3 Future directions*

A qualitative survey of Flemish companies indicated that engineers often take decisions within the design and production process, as well as on the value chain of environmentally sustainable products and services, which served as an argument to focus the EHE kit on these profiles. However, there are other profiles that are also important decision makers in the design and production process, such as employees with an educational background in economic degrees. OVAM has therefore decided to broaden the EHE kit with learning content that is more relevant for economic profiles. This new EHE kit will be available by the end of 2016.

## 6 Conclusion

This article discusses the application of the EHE kit, which provides a hands-on guide for educators and educational supervisors to work on the integration of ecodesign and sustainability in curricula. 19 working sessions have been organised for 17 different educational programmes in higher education in Flanders, in which more than 180 educators participated. Several educational programmes have adapted their curricula as a result of these working sessions. Other educational programmes indicated that the working session triggered them to work on the integration of sustainability in the future. Applying the toolkit provides valuable insights on the use of the toolkit and different circumstances that affect the integration of ecodesign in the curriculum, such as the importance of the role of decision makers to make changes to a curriculum happen. Next to that, organizing free working sessions with the EHE kit under the guidance of experts can help convince educators to work on integrating ecodesign and sustainability in the curriculum. However, the working sessions also clearly indicated that awareness about sustainability still has to increase amongst many educators. Suggestions that came forward for supporting the integration of ecodesign and sustainability are keeping a good connection with business activities, case based education and making the integration of sustainability in higher education mandatory. In general, the application of the EHE kit clearly indicates that exchanging experiences between universities, university colleges and educators is of great importance for the integration of ecodesign and sustainability in higher education. This will on its turn support a shift towards a circular economy.

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# Preparing for the Circular Economy:the role of design and engineering education in Ireland in its implimentation

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## Abstract

The Circular Economy (CE) is the latest iteration of an emerging paradigm of sustainable production and consumption. From a policy perspective the CE is seen as an approach to reducing raw material and energy dependency, improving the supply security of critical raw materials, reducing greenhouse gas emissions while also providing opportunities for economic growth. In doing so it is seen as an opportunity to address the existing market failures of linear production while resolving the ongoing tensions between industrial, innovation and environmental policy.

From an engineering and design perspective, the CE, as it is currently framed in EU policy, appears to provide little in the way of new challenges. It is predominantly presented as a technical concern, the solutions to which have been explored for many years. For example, it demands that full life cycle environmental impacts are designed out of products and buildings, products be kept in use for longer with reduced material and energy inputs and end-of-life processing is as efficient as possible.

Gaps with the current approaches and constraints on the growth of the CE approach are noted by the authors. These include the need for multi-level policy innovation, collaboration and co-production of policy, social innovation and service design. Additionally, while the CE has macro-economic and transnational dimensions, the implementation will occur at a national and sub-national level and this demands changes in individual, business, institutional and societal behaviour. How these different forms of behaviour change are facilitated by either design or policy are not well understood in the context of the CE.

To address this, the principle of the quadruple helix has been presented, mainly in the context of open innovation. Helix models provide useful frameworks to consider the nature of interactions and collaborations however they provide little basis on the specific actions to take and what the implications are for design and engineering.

This paper reflects upon gaps and constraints with specific reference to engineering and design education. This will be in part based on the available literature but augmented through insights from an ongoing research project into co-design for sustainable behaviour change and dialogue with engineering and design educators across Ireland. The paper will present the current state of play of design and engineering education in Ireland with regards the CE and speculate on possible actions and strategies for the future at a national and sub-national level.

## 1. Introduction

Design and engineering play important roles within the CE. For the purposes of this paper we consider design to include product design, service design, interaction design, fashion design and the design of business models. Much emphasis has been placed on the scope for leveraging design to bring about changes in consumption and production behaviours. A number of strategies have been explored over the years, for example how to design products so they retain their material value for as long as possible and how services can be designed to replace or increase the lifetime of products. These strategies have all had practical design and engineering implications in that they may require design for disassembly, using standard components, recyclable materials or changing consumer behaviours to enabling greater repair, reuse, remanufacturing and recycling.

It is important to stress that many of the basic principles of the CE have been applied for decades. For example, remanufacturing has been applied in sectors with high value manufactured components, reuse and repair has been occurring within both formal and informal economies (e.g. Repair shops, Hacker Spaces), shared services providing access rather than ownership and municipal recycling rates have been increasing globally. More recently, technology is facilitating the expansion of service and access models e.g. Car sharing services and peer-to-peer lending. These again have design and engineering implications in terms of designing in durability as well as designing for interaction, transaction and access.

## 2 The Irish Context

Like all regions, the systems of consumption and production in Ireland have diverse environmental, social and economic impacts. The Irish regulatory system has sought to transition to a more sustainable or CE through command and control of unsustainable activities, internalising external costs (e.g. pollution) and create functioning markets for more sustainable technologies. Alongside regulation, Irish NGOs and sections of the public have called for fundamental changes in lifestyles, business models and structural aspects of our economies in order to make production and consumption more sustainable.

While Ireland has no single policy on the CE there is the very beginning of a policy framework that is setting the policy conditions for a CE in Ireland. The framework include national strategies such as “Towards a Resource Efficient Ireland: A National Strategy to 2020”, regional waste plans, business support programmes (e.g. Green Business Programme, SMILE resource Exchange, Stop Food Waste). Clearly this is limited in scope and the situation is further weakened by a lack of research and evidence for developing a CE in Ireland.

There have been many successes in relation to waste prevention but also a clear recognition of the limitations of current approaches. The concept of the CE presents a number of challenges to Ireland not least the fact that Ireland is a relatively small island that is highly reliant on imported goods and energy. For example, Ireland has to import over 80% of its energy supply and this makes Ireland exposed to global instabilities in a number of areas such as critical resource supply and energy prices.

## 3 Method

This paper included a summary review of 36 design and engineering courses within the republic of Ireland to establish if there had been any change since a 2009 study by de Eyto. Significantly the summary review covered a broader range of courses from Engineering, Architecture, Furniture, Interior and Product Design. In addition, the research reviews the responses of a range of industry and society stakeholders to evaluate their response to CE as a developing policy area.

Two online short form qualitative questionnaires were circulated to key stakeholders in Education, Industry and Society. The educator's questionnaire was circulated to 36 course directors, heads of department or module leaders to gage the current approach to CE within HE Design & Engineering courses. The non-educators questionnaire was circulated to 28 key stakeholders from policy and public sector staff within the environmental policy field along with consultants with a speciality in CE or resource management.

## 4 Design and Engineering Education in Ireland

Irish Third Level education is diverse in terms of scale and geographic distribution. In terms of key providers, there are seven Universities, five third level colleges, fourteen Institutes of Technology as well as nine private, independent and not-for-profit colleges. Figure 1 provides an overview of how many of these institute teach design and engineering. We included architecture due to its relationship with both design and engineering.

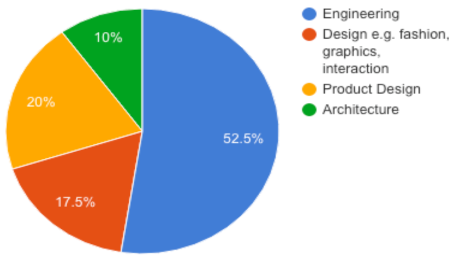


Figure 1: Design & Engineering Education distribution in Irish HE Institutions

In 2014 there were 7,443 graduates from Irish Higher Education Institutes across the disciplines of design, engineering, architecture and construction. The greatest proportion of these were engineering graduates (5,994). Figure 2 provides an overview of the number of graduates across each discipline area.

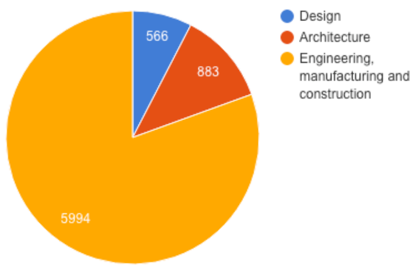


Fig 2: Graduating numbers in Design & Engineering within Ireland (2015)

Design and Engineering courses vary greatly in focus throughout the Higher Education (HE) system in Ireland. Undergraduate degrees provide a general education in the discipline of choice based on differentiations between module structure, course philosophy and the course teams who deliver on the programmes. Product Design, Mechanical, Electrical and Civil Engineering, Architecture and Interiors all form the base disciplines through which graduates specialise.

Taught Masters degrees specialise further with niche focus on current societal or industry trends in Design and Engineering. To date there are no undergraduate degrees in Design or Engineering that specifically specialise in CE principles. There are however a range of undergraduate degrees that have introduced specialist modules in Design for Sustainability (DfS), Life Cycle Engineering (LCE) and similar elements connected to Sustainable Development (SD). Other programs have chosen to integrate DfS or LCE principles within various modules in a non-explicit manner in an effort to allow it become part of the skillset and vocabulary of graduate designers and engineers. Research work undertaken between 2006 and 2009 by one of the authors here indicated a low level of inclusion at that stage of any SD specialisms within Design & Engineering curricula in Ireland (de Eyto,2010). Lack of understanding and knowledge around DfS or CE principles along with a low level of industry demand were cited as key limitations preventing the development of such specialities. A small number of taught master's programs did develop from 2008 onwards through Dublin Institute of Technology and Institute of Technology Carlow which specialised in broader SD specialism and more specific DfS.

In the 2006-09 study, five third level institutes (See **Error! Reference source not found.**) were chosen in the Republic of Ireland which offer 3D design degrees (including Product and Industrial Design).This was by no means a comprehensive reflection of all the courses that were on offer throughout the republic however it was sufficient in terms of more detailed comparison. All the courses outlined tended to follow the traditional design education route of problem and project-based learning. Of these five only two (University of Limerick & Institute of Technology Carlow) offered formal modules or courses in sustainability with a project/lecture mix being the preferred method of delivery in both cases. There are many reasons why sustainability was not taught in the other institutes, the main being that the expertise amongst the staff is not available. However, there was an obvious willingness amongst the lecturing staff in most cases to look externally for this expertise. In the final two years of the study there was some evidence of capacity building in National College of Art and Design and to a lesser extent Sligo IT in terms of sustainable design teaching.

## 5 Policy

A key role for policymakers is enabling the transition to a CE and, as appropriate, help co-create the vision and direction for a CE. To achieve this, policy makers need to:

- Address system and market failures, imperfect information (e.g. for businesses to repair, disassemble and remanufacture products) and unaccounted externalities (e.g. carbon emissions)
- Rectify regulatory barriers (e.g. definitions of waste that hinder trade and transport of products for remanufacturing)
- Co-create appropriate right enabling conditions for the CE (e.g. regulations, incentives)
- Actively steering and stimulating market activity by setting targets, sustainable public procurement, phasing out unsustainable products, facilitating sustainable behaviour in the public
- Invest in innovative pilots, sustainable and socially innovative start-ups and sustainable R&D.
- Promoting market for secondary raw materials, reuse and repair
- Reduce the cost of doing (circular) business.

It is clear from the data gathered from educators and industry stakeholders that policy at an EU level often changes much faster than the ability of HE to respond. Local policy at an Irish Government level is typically reacting to new directives and directions proposed by the EU and so there tends to be a time lag before policy is implemented at a national level.
If one considers that a typical undergraduate or Masters program can take up to 2 years to develop and seek approval this, then translates to a 4-6 year period before graduates from such a course are in a position to enter the workforce. Figure 3 expresses the time lag relationship between policy development and implementation at an EU and National level. Evidence from this study would suggest that Education occasionally leads the way, influencing thinking and policy direction from a research perspective but often lags behind in terms of specific new course development in response to same.

Current EU policy has not radically shifted in its approach and remains tied to the core focus on waste minimisation, and a reduce, reuse and recycle strategy. There is mention in the proposed EU Waste Directive amendment (COM2015) of an aspiration to move towards a CE but little by way of tangible efforts to enable this. Some of the non educational respondents in this study pointed to position statements (Eurochambres 2015) being adopted by industry groupings in response to the changing EU directive however there was also no clear consensus from the sample on how best to respond vague national and EU aspirations around CE.

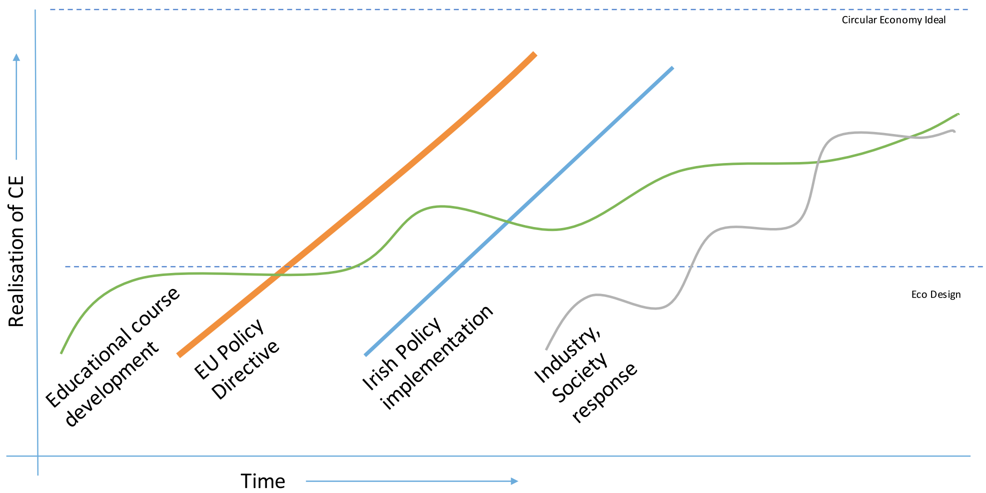


Fig 3: Time lag for implementation of CE between Policy, Industry and Education

## 6 Discussion

The CE demands a more systematic approach to addressing full life cycle impacts of production and consumption. This in turn demands the effective dissemination of knowledge between policy, industry and the wider public. Currently in Ireland there is little structured coordination of knowledge on the CE. In addition to this, there is there is a relatively under-resourced network of business support and no dedicated knowledge exchange network relevant to the CE.

Triple-helix collaboration refers to the situation wherein there is multi-level collaboration between industry, academia and government. The development of triple helix collaboration could impact on the successful implementation of a national CE policy in Ireland. If we include the social dimension of the CE, sustainable consumption or behavior change, we would need to consider the involvement of civil society organisations. Based on a review of the prospectuses and our survey of academic staff there are indications that curricula related to the CE are under-developed. If universities and colleges in Ireland are to become thought leaders and key providers of knowledge and technical competencies relevant to the CE there will need to be a coherent strategy around Curriculum development and research.

Our survey of Academics (n=40) had a response rate of 17.5% and our survey for non-Academics (n=28) had a response rate of 32%. This represents a small qualitative sample however it is clear from the comments by the respondents that there is some agreement that CE is important as both an educational topic and as an industry and societal need. What is less clear is what should be done to improve the response to policy directions. Academics involved with DfS and SD education in Design and Engineering clearly point to the need to develop the knowledge and skillsets of their graduates with respect to CE but they see this as part of a broader range of skills necessary for graduates.

There is also a evidence from the study that some respondents from both sectors see CE as the latest iteration of what was previously referred to variously as Cradle to Cradle, Eco Design, DfS and Resource Management. This interchangability of terms further confuses the response to EU policy but does reflected the shift away from older simplified linear approaches to environmental impact reduction to include more cyclical thinking around resource re-use, societal impact and economic benefit.

## 7 Summary

Initial Insights from the research suggest that there of a small number of educators and policy makers who have a vision for how a more sustainable economy can be developed in Ireland. Typically many of these are individuals or small teams of like minded individuals who collaborate within and across the confines of their organisations to move ahead of EU policy and imagine new directions for SD/DfS & CE.

What is also clear from the research is that the support structures to develop educational policy, government policy and EU policy directives are limited. Research grant funding, long term strategic planning funding and support for the development of more formal interagency collaboration structures needs to be allocated specifically to the development of CE if it is to be uccessfully implemented

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There is a clear opportunity for a number of the key educational institutions to develop specifc Masters modules and full programs which can respond to the lack of graduate capacity in this area however this needs to be tackled in a collaborative manner, co-designing curricula and developing 'studio' and 'project' led courses which work in real time with state agencies, societal stakeholders and policy makers

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# Developing a Cross-Disciplinary Sustainable Design Rubric for Engineering Projects

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## Abstract

Sustainable development poses a challenge for all engineers, regardless of discipline, to improve the design of infrastructure, products, and processes. In order to provide undergraduate engineering students with a strong, consistent foundation in sustainability principles to frame and guide design decisions, new educational tools need to be developed and validated. One approach to stimulating both student learning and assessment is the use of rubrics. Rubrics can be used to evaluate the quality of student products like homework, reports, presentations, prototypes, etc. They can also be used prior to assignments to help students learn about different dimensions of sustainability, establish expectations for sustainable design, and self-assess how well principles were applied to design projects. In prior work, the authors developed a sustainable design rubric by decomposing and supplementing the Nine Principles of Green Engineering to aid in quantifying students' abilities to incorporate sustainability into design projects. The rubric was successfully used to assess undergraduate civil and environmental engineering capstone design projects at a research-intensive university. In order to apply the rubric more broadly across engineering projects, it needs to capture criteria reflective of multiple engineering disciplines. The development of a new rubric for cross-disciplinary application begins with a systematic literature review of academic and industry publications is used to distil principles of "Engineering Sustainability" and "Sustainable Design." Principles of sustainable design are typically framed from the point of view of a particular discipline; for example, "Green Engineering" from Chemical/Environmental Engineering or "Design for Environment" from Mechanical Engineering. Additionally, professional societies and organizations have created sustainability rating systems or credentialing for professionals. The literature review synthesizes potential design criteria that are consistent across disciplines, like lifecycle considerations, along with criteria that are applicable to particular engineering applications. In future phases, the rubric development will use a multi-disciplinary expert panel to validate the content of criteria. Finally, the authors will test and evaluate the rubric's application to a diverse set of student design projects.

## 1 Introduction

Because engineers are increasingly called upon to develop sustainable solutions, it has become imperative to adapt engineering education to equip students with the knowledge and skills to engage in sustainable design (e.g., Bauer *et al*., 2012). Current curricula in higher education tend to emphasize disciplinary specialization and reductionist thinking. As a result, many students are "unbalanced, over-specialized, and mono-disciplinary graduates" who use their specific skill sets to solve problems by analysing system components in isolation (Lozano, 2010). In contrast, the complex nature of global and local dilemmas necessitates that sustainable engineers exercise interdisciplinary and systems thinking to understand and balance the interrelated technical, economic, environmental, and social dimensions of a problem. For instance, alleviation of global problems of resource scarcity and environmental degradation in the context of a growing population requires a broad knowledge base and the ability to analyse problems holistically (Davidson *et al*., 2007). Recognizing the potential benefits of sustainable engineering, many organizations, including the Accreditation Board for Engineering and Technology (ABET), the American Association of Engineering Societies (AAES), and the American Society of Civil Engineers (ASCE) advocate for curricular reforms.

Successful educational reform efforts first require effective methods for assessing student sustainable design abilities. Some work has been done to analyse the conceptual sustainability knowledge of engineering students using surveys (e.g., Watson *et al*., 2013a) and concept maps (e.g., Barrella & Watson, 2015). While it is critical to ensure that students grasp the complexity of sustainability topics, it is especially important for engineering students to be able to apply this knowledge in the design process. Unfortunately, less discussion in the literature has been devoted to how to assess student sustainable design abilities.

One approach to stimulating both student learning and assessment is the use of rubrics. Rubrics can be used to evaluate the quality of student products like homework, reports, presentations, prototypes, etc. They can also be used prior to assignments to help students learn about different dimensions of sustainability, establish expectations for sustainable design, and self-assess how well principles were applied to design projects. Developing a sustainable design rubric requires a set of criteria by which to judge design performance. A number of rating systems are available for quantifying the sustainability of large infrastructure projects, which may provide insights for judging student projects.

One common practice is to use professional rating systems as frameworks for guiding students in sustainable design of infrastructure. At George Mason University, students in Civil, Environmental, and Infrastructure Engineering were required to design a neighbourhood to achieve at least silver certification based on the Leadership in Energy and Environmental Design (LEED) rating system (deMonsabert & Miller, 2009). Similarly, students in Construction Engineering and Management at King Fahd University of Petroleum and Minerals in Saudi Arabia were required to use the LEED framework to analyse the impacts of sustainable design choices on construction management aspects of a variety of projects (e.g., solar power plant, football stadium, hospital, etc.) (Siddiqui *et al*., 2012). Even still, students in Civil Engineering at the University of Utah completed a sustainability module to introduce them to the sustainability concepts, whole-system thinking, and the Envision rating system from the Institute for Sustainable Infrastructure (Burian & Reynolds, 2014). Ultimately, students were required to apply the Envision rating system to their projects. Assessment of the University of Utah capstone course revealed that the module was effective for teaching students about the rating system, although it did not encourage "deeper learning of general sustainability knowledge" (Burian & Reynolds, 2014).

While professional rating systems serve as useful tools for teaching about sustainable design, they may be too complex for assessment of student-level projects (Watson *et al*., 2013b). In addition, frameworks like LEED and Envision™ are limited to assessment of infrastructure projects and may not be helpful for design of products and processes. The Nine Principles of Sustainable Engineering, however, may serve as a more general framework for engaging in sustainable design. These Principles were developed by a group of sustainable engineering experts gathered at a 2002 Green Engineering Conference held in Sandestin, FL. The intent of proposing the Principles were to "provide a paradigm in which engineers can design products and services to meet societal needs with minimal impact on the global ecosystem" (Abraham, 2006). While the Principles do not outline a sustainable design methodology, they can be used with existing design strategies to produce sustainable projects (Abraham, 2006). In fact, many of the Principles are reflected in both the LEED and Envision™ rating systems. Indeed, the Principles can serve as the foundation of a cross-disciplinary sustainable design rubric for student projects.

The goal of this paper is to outline the development of a cross-disciplinary sustainable design rubric. A previously-developed rubric, based on the Nine Principles of Sustainable Engineering, will be summarized. Next, a systematic literature review of publications will be completed to expand the rubric in a cross-disciplinary context. The resulting rubric is intended to (1) assist students in achieving sustainability requirements in interdisciplinary projects or to different types of problems and (2) assist engineering educators in disciplinary and general engineering departments with sustainable design instruction and assessment of course or program outcomes. Future work will include validation of the cross-disciplinary rubric by an expert panel and subsequent application to a diverse set of student design projects.

## 2 Review of Prior Work

### *2.1 Summary of Existing Sustainable Design Rubric*

A sustainable design rubric was previously developed based on the Nine Principles of Sustainable Engineering for application in civil and environmental engineering (CEE) courses (Watson *et al.*, 2013b). Since many of the Nine Principles are complex and incorporate multiple ideas, each principle was decomposed into discrete design criteria to aid in ease of rubric application. Because the economic dimension of sustainability is not explicitly represented by the Nine Principles, the set of 13 criteria was supplemented with three economic design criteria. As a result, a system of 16 sustainable design criteria was established (Table 1).

Two four-point rating scales were created to aid evaluators in judging capstone reports based on the 16 sustainable design criteria (Table 2). The earned points scale captures the extent to which students consider each sustainable design criterion in their capstone projects. Evaluators assign a score of 0 to projects that show no evidence of incorporating the design criterion, while a score of 3 is assigned if the project shows evidence of extensive criterion application. The potential points scale describes the extent to which each sustainable design criterion is applicable to a given capstone project. Evaluators assign a score of 0 if the criterion is not applicable to the project. A score of 3 is assigned if the criterion is applicable, as well as required by an instructor or project sponsor. Rating projects on both the extent of consideration and level of applicability allows for differentiation between sustainability application due to student motivation and external requests.

Table 1: Sample scoring rubric used to evaluate capstone design projects.

| Design Criteria | Potential Points | Earned Points |
|---|---|---|
| Environmental Design Criteria | | |
| 1. Minimizes natural resource depletion. | 1-3 | 0-3 |
| 2. Prevents waste. | 1-3 | 0-3 |
| 3. Protects natural ecosystems. | 1-3 | 0-3 |
| 4. Uses renewable energy sources. | 1-3 | 0-3 |
| 5. Uses inherently safe and benign materials (to environment). | 1-3 | 0-3 |
| Social Design Criteria | | |

| | | |
|---|---|---|
| 6. Addresses community and stakeholder requests. | 1-3 | 0-3 |
| 7. Considers local circumstances and cultures. | 1-3 | 0-3 |
| 8. Protects human health and well-being. | 1-3 | 3 |
| 9. Uses inherently safe and benign materials (to humans). | 1-3 | 0-3 |
| Sustainable Design Tools | | |
| 10. Incorporates life cycle analysis. | 1-3 | 0-3 |
| 11. Incorporates environmental impact assessment tools. | 1-3 | 0-3 |
| 12. Incorporates systems analysis. | 1-3 | 0-3 |
| 13. Uses innovative technologies to achieve sustainability. | 1-3 | 0-3 |
| Economic Design Criteria | | |
| 14. Consider economic impacts of applying environmental design criteria. | 1-3 | 0-3 |
| 15. Consider economic impacts of applying social design criteria. | 1-3 | 0-3 |
| 16. Conduct a cost and/or cost-benefit analysis. | 1-3 | 2 |

Table 2: Rating scale for extent of consideration of sustainable design criteria (earned points) and the level of applicability of sustainable design criteria (potential points).

| Earned Score | Descriptor | Dimension Description |
|---|---|---|
| 0 | Unacceptable | Criterion not at all considered in project report. |
| 1 | Developing | Criterion mentioned or discussed in the project report, but not applied in design process. |
| 2 | Competent | Project report shows evidence that the criterion was adequately applied in design process (1-2 instances of criterion application). |
| 3 | Exemplary | Project report shows evidence that the criterion was extensively applied in the design process (3 or more instances of criterion application). |
| **Potential Score** | **Descriptor** | **Dimension Description** |
| 0 | Inapplicable | The criterion is not at all valid for the project. |
| 1 | Valid | Although the sponsor does not require application of the criterion, it is still applicable to the project. |
| 2 | Required | The sponsor requires some application of the criterion in the project (1-2 instances of requiring criterion application). |
| 3 | Critical | The sponsor requires extensive application of the criterion in the project (3 or more instances of requiring criterion application). |

A set of 40 CEE capstone design projects were scored by three expert judges using the sustainable design rubric. After the project, several improvements to the rubric were noted, especially related to the social design criteria. Specifically, criteria should be added and reinterpreted to distinguish between required elements of design that benefit stakeholders and truly innovative practices that go beyond the norm to achieve social sustainability. For instance, in the future, consideration of safety during design may not be interpreted as "promoting human health and well-being," as was done in the previous study. Rather, actions to ensure the safety of the public, which are required for most projects, may be captured in a new "ensures safety during the design process" criterion. Creation of this new criterion would allow the "promotes human health and well-being category" to capture non-safety related actions that are often not required of engineers. Second, the "addresses community and stakeholder requests" criterion should also be re-interpreted. Students received credit for meeting the needs of their project sponsors, as well as those of broader stakeholders. While it was not possible for students to receive the maximum earned score by only addressing technical stakeholders' needs, they were given credit for such efforts. Perhaps a re-interpretation of the earned points scale for this criterion, or a creation of a new sponsor-specific criterion, would more clearly capture students' efforts to ensure inclusiveness during the design process. Changes to social design criteria would overall make the rubric more transparent.

## 3 Methodology for Rubric Revision

In addition to the aforementioned limitations, there is an opportunity to refine the rubric and scoring process to broaden applicability to engineering design projects outside of civil and environmental engineering. In order to apply the rubric more broadly across engineering projects, it needs to capture criteria reflective of multiple engineering disciplines and be flexible in how criteria are weighted and evaluated. In order to validate the constructs of sustainable design and their measures (Benson, 1998), the development of a new rubric for cross-disciplinary application incorporates three key phases in order to validate the constructs and their measures: First, a systematic literature review of academic and industry publications is used to distil principles of "engineering sustainability" and "sustainable design." The literature review in the next section synthesizes potential design criteria that are consistent across disciplines, like lifecycle considerations, along with criteria that are applicable to particular engineering applications. Second, the preliminary criteria will be reviewed, categorized, and prioritized by a multi-disciplinary expert panel to validate the content of the rubric (Davis, 1992). Third, Analytic Hierarchy Process, a multi-objective decision-making methodology, (Saaty, 1982; Dieter & Schmidt, 2012) will guide the determination of potential points for the rubric criteria distilled in the first two steps. After construct validation, the rubric will be tested on a diverse set of projects.

## 4 Systematic Literature Review and Distillation of Principles

A systematic literature review is a tool in engineering education research, and more broadly scientific research, for identifying patterns and relationships in published work in order to build upon prior findings (Borrego *et al.*, 2014; Penzenstadler *et al.*, 2012). In light of the growing volume of engineering education and sustainability education publications, a systematic literature review provided a means of prioritizing the most relevant and seminal works. The systematic literature review followed five steps, similar to other reviews in the field, as shown in Figure 1.

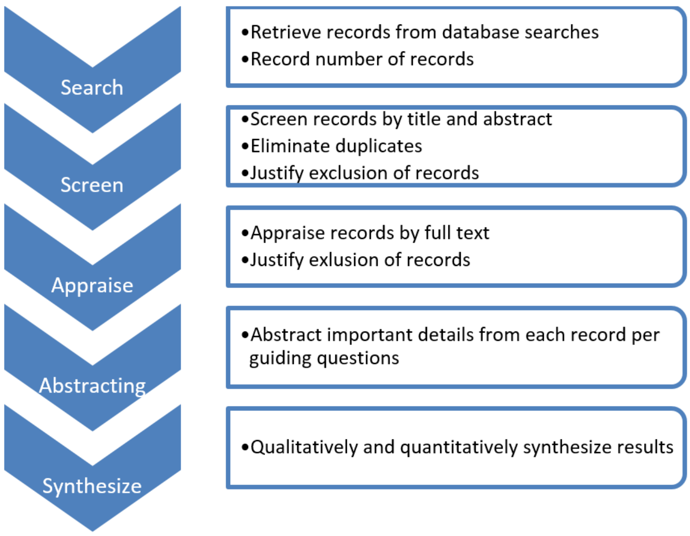


Figure 1. Systematic literature review process for this study (based on Borrego et al., 2014)

The preliminary search was conducted in the three databases that index journals and conference proceedings relevant to this study: Academic Search Complete, Education Research Complete, and Environment Complete. Five searches were conducted in order to capture different disciplinary perspectives and results are classified as non-discipline specific (Engineering), civil engineering, mechanical engineering/product design/manufacturing, electrical/electronics/computer engineering, or chemical/green Engineering. For each search, the following search terms and structure was used: *[add discipline keyword]* engineering AND education AND sustainability OR sustainable design. Searches were restricted to scholarly (peer reviewed) works and from 2010-2016 in order to capture seminal works completed after the first rubric's development and testing. The first 100 records resulting from each search, ordered by relevance, were screened. The search results in the first three phases are summarized in Table 3.

Table 3: Summary of systematic literature review.

| | Non-discipline | Civil | Mechanical | Electrical | Chemical |
|---|---|---|---|---|---|
| Search Results | 15,381 | 14,156 | 14,349 | 14,371 | 14,459 |
| Screening | 56 retained | 47 retained | 23 retained | 12 retained | 18 retained |
| Appraisal | 54 retained | N/A | 20 retained | 10 retained | 15 retained |

Papers that were retained after the appraisal stage were reviewed in more depth in order to extract key principles of sustainability and sustainable design that are pertinent to evaluating engineering design projects in the different disciplines. This deeper review focused on distilling sustainable design principles from mechanical, electrical, and chemical engineering-oriented studies in order to supplement prior work which focused on civil and environmental engineering coursework. In addition to the articles identified in the systematic search and review, targeted searches of engineering education and discipline-specific databases (American Society of Engineering Education's Papers on Engineering Education Repository (PEER) and IEEE Xplore Digital Library) were used to supplement searches that returned few substantive results. This supplemental search resulted in five additional mechanical/manufacturing papers and 11 additional electrical/computer/control systems papers. A supplemental search was not conducted on chemical engineering because Principles of Green Engineering were prevalent in the non-discipline specific search results.

Content analysis of key principles indicates alignment with many of the criteria contained in the prior Sustainable Design Rubric. Literature from all disciplines emphasized the use of tools, especially life cycle assessments, to operationalize sustainability. Several works also referred to the importance of ensuring the safety of users, a theme which is included in the current social design criteria. Additional elements of the social design criteria were also identified in the literature. Across disciplines, stakeholder participation and/or public involvement were key themes. In addition, many authors cited the need for students to understand the social context of their designs.

Emphasis on protecting the natural environment abounded in the examined literature, which aligns with the environmental design criteria of the rubric. However, the cross-disciplinary literature examined certainly had an emphasis on carbon emissions and related environmental impacts. For example, electrical and product-related engineering manuscripts often cited the importance of a low-carbon economy. Across disciplines, carbon footprints were used as measures of overall environmental impact. Literature related to electronics often prioritized low-energy production, which correlates to the "minimize natural resource depletion" criterion in the existing rubric.

Interestingly, economic aspects of sustainability were infrequently discussed in the examined literature. Indeed, in the first iteration of the Sustainable Design Rubric, economic criteria were added independently, since they were neglected in the original Nine Principles of Sustainable Design. The most common themes related to economic sustainability were elements of cost competitiveness and cost reduction reflected in the mechanical and product-related engineering literature.

Several themes (see Figure 2) from the cross-disciplinary literature are not reflected in the Sustainable Design Rubric. Across disciplines, themes of ethics, affordability and equity, as well as innovation emerged from the literature. From chemical engineering literature, many key themes were already reflected in the rubric, with the exception of uncertainty. Several key themes found in the electrical and mechanical engineering literature are currently not reflected in rubric, including industrial ecology, technological adaptability, e-waste, and user experience. In addition, design for “X” (DfX) approaches, such as design for disassembly, were commonly discussed in the electrical and mechanical literature.

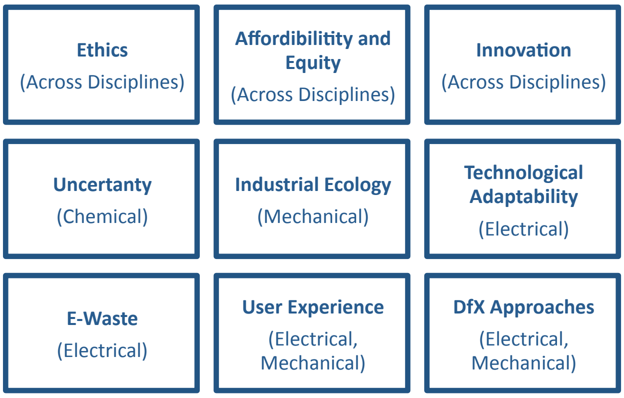


Figure 2: Summary of themes currently not reflected in the Sustainable Design Rubric

## 5 Future Work

Upcoming work will be completed in several stages to produce a cross-disciplinary sustainable design rubric. First, additional manuscripts will be added as part of the systematic literature review, especially those from civil engineering. Second, additional themes identified as part of the systematic literature review (Figure 1) will be translated into design criteria. Third, an expert panel will be convened to validate the sustainable design criteria.

## Acknowledgement

Support for this study was provided by NSF#1463865 *Developing and Assessing Engineering Students' Cognitive Flexibility in the Domain of Sustainable Design*. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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# Training Engineers for Handling Ethical Dilemmas in Sustainability Contexts

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## Abstract

With recent industrial scandals like the Volkswagen emission test manipulations, it is clear that engineering professionals need a more solid foundation for conscious reflection on ethics in the profession. Further, with the mainstreaming of education for sustainable development (ESD) in engineering education, students increasingly meet problems with inherent value conflicts in their education. This presents a challenge as well as an opportunity.

The Swedish System of Qualifications for engineers includes a learning outcome on engineering ethics. Students who achieve the Master's degree should have the ”ability to formulate judgments, within the field of study, that include reflection on relevant ethical issues”. According to the last national review by the Agency for Higher Education in 2012, this requirement is not completely fulfilled in many educational programmes.

There is a long tradition at Chalmers University of Technology to address sustainable development in the study programmes. However, the focus is commonly on the environmental dimension of sustainable development, and the social dimension and ethics are not included to the same extent. Many teachers express that they find it difficult to design appropriate learning situations that support students' learning in ethics, and to design assessments that measure how well students fulfil intended learning outcomes. The situation is similar at other universities. Thus, there is a need to spread good examples on how ethics can be integrated in education to inspire and facilitate for teachers.

In this paper, we suggest a framework for how learning in engineering ethics can be supported by means of a focus on ethical dilemmas in a tiered approach with three elements. Ethical dilemmas are situations in which there is a choice to be made between different options, and where neither of these options is optimal from an ethical perspective. We also provide characteristics and examples of ethical dilemmas appropriate to use at different levels.

## 1 Introduction

In an increasingly technology-based and globalised society, human actions have an increasing potential to affect humans and ecosystems both locally and globally, also far away from the action. With the simultaneous increase in the use of information and communication technology, our knowledge on such impacts is also increasing and different ethical issues regularly surface in media. One recent example that gained global media coverage is the Volkswagen emission test manipulations. Other well-known examples on the disclosure of governmental and corporate misconduct includes the covert surveillance program revealed by the so-called *whistle-blower* Edward Snowden and the leaking of secret documents by the WikiLeaks organization.

The perceived roles of citizens and of engineering professionals have shifted over time and between societies. In sustainable development discussions, the responsibility of individual citizens and individual professionals to react to and act upon ethical issues is emphasised. However, there are also people and cultures that consider for example technology to be neutral and where the responsibility is not considered to fall upon the developer of technology but rather on other stakeholders in society, primarily policymakers and users. These differing views on the role of the citizen and of professionals create both tension and uncertainty for individuals on the appropriate way to deal with ethical issues. To guide professionals, *ethical codes* have been formulated by organizations and corporate entities. For engineering professionals, some examples of ethical codes are the ones by the US National Society for Professional Engineers (www.nspe.org/resources/ethics/code-ethics), the UK Royal Academy of Engineering (www.raeng.org.uk/policy/engineering-ethics/ethics) and Engineers Australia (www.engineersaustralia.org.au//sites/default/files/shado/About%20Us/Overview/Governance/codeofethics2010.pdf). An engineer is also expected to follow any corporate *code of conduct* that may apply. So, there is some guidance for engineers that encounter ethical issues, but how to interpret these codes and how to manage ethical conflicts (or dilemmas) that may arise is not straight-forward. Also, if the engineer does not have the mind-set that there may be ethical issues in relation to his or her activities and that he or she has the responsibility to deal with them, the codes will likely not be consulted and will not have much impact.

The importance of preparing engineers for ethical considerations has been increasingly emphasised as manifested by the increasing number of engineering programmes that include *engineering ethics* in their curricula and by the number of accreditation agencies that require this. In Sweden, for example, there are requirements for ethics in engineering education according to the Swedish System of Qualifications for Master's degrees (Ministry of Education, 2006), stating that students should "have the ability to make judgments, within the field of study, with respect to relevant ethical issues, and to demonstrate an awareness of ethical aspects of research and development". Other movements that push for the introduction of engineering ethics is the strengthening of generic and transferrable skills and the inclusion of science, technology and society (STS) elements in education. Further, concurrent efforts to integrate education for sustainable development into engineering education highlight the need for students to manage the potential trade-offs between different dimensions of sustainability and the responsibility to consider and protect ecosystems, the well-being of all people, now and in the future, and other aspects of human society such as economy, cultures, knowledge etcetera. Thus, sustainability requires that engineers are able to manage ethical issues. But also, dealing with sustainability in education creates opportunities to discuss ethical issues as these will almost always be present in discussions around sustainability.

*Ethical dilemmas* can be an effective tool in education to support students' motivation and learning about ethics, since they give an opportunity for students to deal with issues they can face in their profession (Harris *et al.*, 1997; Lynch & Kline, 2000). An *ethical dilemma* is a situation where two or more norms or moral judgements are in conflict with each other and cannot be fully realised at the same time. Other denominations of such situations are *moral dilemmas* or *moral problems* (Hansson, 2009, van de Poel & Royakkers, 2007). There is ample access to fictive and authentic ethical dilemmas (see for example, National Academy of Engineering, 2016). These are often divided into different topics or fields of engineering. Even so, it may not be so easy for teachers to know what kind of ethical dilemmas that are the most relevant and useful for their specific courses and how to use them in education. Hence, there is a need to support teachers in how to choose among ethical dilemmas and how to use them in their teaching.

The aim of this paper is to provide support to teachers in higher education in teaching engineering ethics by integrating considerations on ethical dilemmas in education. The objectives are to present a framework for this integration, which includes characteristics of ethical dilemmas appropriate in different teaching activities, and to present examples of ethical dilemmas and how they are used in courses based on this framework.

## 2 Theory and method

Some characteristics of sustainability issues are that they are long-term, global and cross-boundary. Sustainability issues can be described as embedded in *wicked* systems (Rittel & Webber, 1973), making these issues so-called *wicked problems* or *ill-structured problems* (Jonassen *et al.*, 2006). Such problems involve a high degree of uncertainty, lack definite right or wrong solutions, are highly contextualized, involve political considerations and are characterized by a high level of inherent ambiguity and normative conflict (Lönngren & Svanström, 2015). Bringing sustainability issues into education therefore also presents an excellent opportunity to practice dealing with ethical dilemmas. According to Lynch & Kline (2000), ethical dilemmas should be formulated to reflect the complex and open conditions that exist in engineering practice to make them the most effective in education. One way to do this could be to integrate ethics in courses that include projects in authentic contexts. Thus, this is an argument for integrating ethics into courses on engineering topics instead of giving engineering ethics only as separate courses (Harris *et al.*, 1997; Herkert, 2002). Further, it has been shown that integration of sustainability in several courses in a study programme can enhance students' motivation and learning of sustainability compared to study programmes that have only one separate course on sustainability (Hanning *et al.*, 2012). A strategy for education for sustainable development at Chalmers University of Technology (Chalmers) in Gothenburg, Sweden, has therefore been to have several courses in a study programme in which sustainability is integrated in addition to a separate course in sustainability (Enelund *et al.*, 2012). Thus, in the suggested framework for how to use ethical dilemmas in education, described in this paper, engineering ethics is integrated in several courses in a study programme. This allows both for the connection to the specialisation to make this content relevant for the students and for progression in learning throughout the programme.

The CDIO (conceive, design, implement, operate) Initiative (CDIO Initiative, 2010) provides a framework for the design of engineering education, which, among other things, includes a classification of teaching activities in terms of progression in learning throughout a study programme (Malmqvist *et al.*, 2006):

- *Introduce*: Expose the students to a topic. No explicit learning objectives, no major activities such as assignments, exercises or projects, and no assessment is linked to this topic.
- *Teach*: There is an explicit learning objective. Compulsory activities, such as assignments, exercises or projects are specifically linked to this topic. Student learning is assessed.
- *Utilise*: Assumes students already have some proficiency in this topic, which is utilised mainly to learn and/or assess other learning objectives.

This classification is used as one of the main components for the structure of the suggested framework.

*Constructive alignment* (Biggs & Tang, 2007) is another main component in the structure of the framework. Constructive alignment is about the alignment between intended learning outcomes, teaching and learning situations, and assessment of learning in a course, and based on constructivism, i.e., that students learn best when they are active. Teaching situations should support student's learning of the intended learning outcomes and the assessment should assess that the students have learnt what they were supposed to learn based on the intended learning outcomes.

The framework suggested in this paper for how to use ethical dilemmas in education also suggest levels of learning, using the six levels in *Bloom's taxonomy* for the cognitive domain (Bloom *et al.*, 1956):

- *Knowledge*: Recall previously learned information.
- *Comprehension*: Demonstrate an understanding of the meaning or purpose of previously learned information.
- *Application*: Use previously learned information in novel and concrete situations.
- *Analysis*: Examine the underlying components of learned information and gain an understanding of their organizational structure. This level also includes making inferences and using the information to support broader generalizations.
- *Synthesis*: Integrate previously learned information and its components into new concepts.
- *Evaluation*: Use definite criteria (either provided or self-created) to judge the value of other material and information.

As an example, the required learning for engineering ethics in the Swedish System of Qualifications for engineers (Ministry of Education, 2006) is "ability to *make judgments*, within the field of study, with respect to relevant ethical issues", which corresponds to the level of *evaluation* in Bloom's taxonomy.

## 3 Framework for the use of ethical dilemmas in education

The framework suggests a progression throughout a study programme in three steps: introduce, teach, and utilise (following the CDIO terminology), which we believe can create and maintain the attention and motivation among students and build relevant competences. These three steps should preferably be integrated into courses in a study programme where ethics can be connected to the course topics in a natural way. Our experience is that it is very important for the motivation of students that they perceive the topic to be relevant for them and their future profession (e.g. Hanning *et al.*, 2012). The suggested framework is presented in Table 1. The table provides characteristics of ethical dilemmas appropriate to use at the different levels. Examples of ethical dilemmas and how they are used in courses based on this framework are presented in the following sections.

### *3.1 First element: Introduce, first semester*

We suggest that students are exposed to ethical dilemmas early on in their education, preferably already during the first semester. This can awaken their attention to ethical issues and motivate further studies on the matter. When a topic is *introduced*, according to CDIO terminology, there is no need for specific learning outcomes and for assessment of the learning. We suggest, however, that this introduction involves more than just the listening to a lecture or the reading of some material and also includes active participation in discussions or in searching for examples, to adhere to the constructivist idea of constructive alignment. The ethical dilemmas should also be highly relevant for the specialisation and authentic to connect to actual future activities of the students.

This could be done in the form of a seminar where students are asked beforehand to bring a couple of examples of ethical dilemmas that they anticipate to encounter in their professional life and where they also discuss why these are relevant ethical dilemmas and how they could be managed. It could also be in the form of a guest lecture by someone from industry with experience of ethical dilemmas, and during the lecture, students could discuss some possible solutions and then be given the answer to how it was dealt with in practice.

Table 1: Framework for the use of ethical dilemmas in education.

| Order of element | First | Second | Third |
|---|---|---|---|
| CDIO classification of teaching activities | Introduce | Teach | Utilise |
| Focus of learning activity | Students' attention and awareness | Learning of theory and methods | Application in authentic contexts |
| Level of learning according to Bloom's taxonomy | n.a. | Knowledge and comprehension | Application, analysis, synthesis, and evaluation |
| Type of teaching and characteristics of ethical dilemmas | Discussion of authentic and rather detailed ethical dilemmas connected to the profession. | Theory complemented with application on stripped-down ethical dilemmas. | Natural parts of projects in authentic professional settings, which allows the exploration of details in ethical dilemmas. |
| Assessment | Active participation | Written examination or hand-ins | Written reports or oral presentations, with clear assessment criteria |

### *3.2 Second element: Teach, bachelor level*

We further suggest that later on during the bachelor years, students are taught some basic elements of dealing with ethical dilemmas. When *teaching* a topic, according to the CDIO framework, there has to be explicit learning outcomes, a teaching and learning activity that connects to this, and assessment of the learning. We suggest that there is now a focus on theory in terms of what characterises an ethical dilemma, different ethical theories, and on how to apply ethical theories to manage ethical dilemmas. The ethical dilemmas that theories are applied to may need to be stripped-down and simplified to allow for exploration of the theories rather than the dilemmas themselves. If the students have already been exposed to several ethical dilemmas earlier, they may make the connections to real-life activities anyway. A strong connection to the profession is preferable but may not be necessary at this level. Examples of intended learning outcomes for the levels of learning of *knowledge* and *comprehension* according to Bloom's taxonomy could be:

- Explain what an ethical dilemma is
- Explain some basics of ethics theory
- Describe a procedure for ethics analysis

As an example, we describe an element included in the education in some educational programmes at Chalmers. During the second or third bachelor year in four different engineering programmes (MScEng Chemical Engineering, MScEng Chemical Engineering with physics, MScEng Biotechnology and BScEng Chemical Engineering), engineering ethics is part of a course called Chemical Environmental Science or Biochemical Environmental Science. The course focuses on environmental science, chemical risk assessment and environmental management and contains a two-hour lecture on engineering ethics. The intended learning outcome for this course element as described in the course information is that students should be able to “Discuss different ethical principles in decision-making”. In practice, the teaching focuses on explaining what an ethical dilemma is, different ethical principles and a framework for how to use them in analysis of an ethical dilemma. This framework resembles frameworks that have been described earlier by e.g. Svanström & Adawi (2012) and van de Poel & Royakkers (2011).

The teaching starts with a discussion among students on why it is important for an engineer to make ethical judgements in different decisions, to activate the students and motivate the topic. After this, the concept of ethical dilemmas is explained along with different ethical principles that can be used to analyse an ethical dilemma: consequence ethics, virtue and rights ethics, the publicity test, the reciprocity principle and the universality test. The framework that the students are then asked to use in a group exercise focuses on applying these different ethical principles to an ethical dilemma to see what kind of guidance that these different principles provide. Students are divided into groups to work on either of three dilemmas. The students then present their findings to the rest of the class. Finally, the concept of whistle-blowing is introduced along with whistle-blowing policies of companies and the code of ethics of the Swedish Association of Graduate Engineers.

This two-hour lecture is performed in a normal lecture hall with a class of 60-200 students. This means that the level of interaction between individuals and the lecturer is rather low and that students can discuss only with the students that sit closest to them in the group discussions. However, the discussion after the exercise allows the lecturer to correct any misconceptions that come to the surface.

The ethical dilemmas that the students focus on are taken from literature and students are provided only a brief description. One example is the famous authentic ethical issue of a car manufacturer that found out that there was a risk of a gasoline explosion if their cars experienced a collision from behind. They decided not to take measures to fix the problem on the already purchased cars as it was deemed to be cheaper in total for them to manage any future economic claims from customers that had experienced harm (Simons, 1999).

Assessment of learning of this element is by means of questions in the written examination, e.g.:

- What is an ethical dilemma? Provide a clear example that is relevant for your future profession.
- What is a whistle-blower?
- Describe what is meant by consequence ethics.
- Apply the universality test and the reciprocity test to a certain ethical dilemma and discuss the outcome.

### *3.3 Third element: Utilise, Master level*

We suggest the third element should focus on utilising the earlier gained knowledge in an authentic professional context that allows for both identification of ethical dilemmas and exploration and analysis of them. The students therefore need to be able to access sources of information that could enrich their understanding of the dilemma and its context.

Ethical dilemmas that focus on application in authentic contexts are used in the course Applied industrial ecology, which is a course at advanced level in the Master's programme Industrial ecology at Chalmers. The course includes a project where the students perform a technology assessment of an emerging product to answer the question whether this product could be used large-scale and long-term in a sustainable society. The technology assessment includes considerations of the limited availability of resources, including land, and the limited assimilation capacity in nature of emissions from society. The students identify ethical dilemmas themselves, which are typically about the potential conflicts between these limitations and the needs that the services from the products fulfil. Examples of products that have been studied in the course and examples of ethical dilemmas in connection to them are:

- *Organic cotton* causes lower emissions of hazardous substances than traditional cotton. However, it requires more land which could be competing with food production.
- *3D printers* could contribute to reduced transportation and thus reduced emissions. However, a misuse of 3D printers could be to print weapons.
- *Graphene* is an emerging technology that can be useful in many applications. However, large-scale use could give rise to emissions of graphene that could be harmful for people.

The intended learning outcomes for ethics in the course are that the students should be able to:

- identify, describe, and analyze potential ethical concerns for technical systems and life cycles of resources and products
- make an informed evaluation of such potential ethical concerns, based on ethics theory, and construct arguments for how to act.

Not all of the students who take this course have previous knowledge in ethics, which requires that this course includes some teaching in ethics as a complement to the utilisation. The teaching situations in the course includes:

- a presentation of ethics theory, such as utilitarianism and deontological ethics;
- a simple ethical dilemma to understand the difference between ethical theories, which is discussed in smaller groups and then in the whole class;
- a presentation of the Ethical Cycle (van de Poel & Royakkers, 2007; 2011), which is a systematic method for performing ethical analysis in decision-making.

Students apply the Ethical Cycle in their projects to reach a decision, including arguments for this decision, for how society should act when it comes to the emerging products that they are studying. The learning is supported by supervision by a teacher.

The assessment in the course is done by oral presentation and a short written report of the project as well as a written examination. Criteria for how well the students have been able to perform the ethics analysis is used for the assessment of the project, and there can be questions about ethics theory and the methodology for the Ethical Cycle in the exam.

## 4 Discussion and conclusions

We have suggested a framework for the use of ethical dilemmas in education, which includes three steps for the integration of ethics to allow for progression throughout a programme. Study programme directors and teachers can use this framework to get support in integrating ethics in education. In the framework, we emphasise the differences between the use of ethical dilemmas in three steps when it comes to: focus, level of learning, teaching, and assessment. Some important characteristics of ethical dilemmas in teaching are their *level of detail* and their *connection to the profession*. A high level of detail and a strong connection to the profession is particularly important in the *introduction* and *utilisation* of ethical dilemmas, while there can be less detail and less connection to the profession during the use of ethical dilemmas in *teaching*.

We suggest that published examples of ethical dilemmas should be sorted not just into different topics or fields of engineering but also into different *levels of detail*, since this would facilitate for teachers to find relevant ethical dilemmas for their courses among the vast number of dilemmas that have been published.

There is a strong synergy between education for sustainable development and teaching engineering ethics. In this paper, we have showed some examples of how ethics can be integrated in a natural way in courses in environment and sustainable development. However, all ethical dilemmas cannot be classified as sustainability issues. But, general knowledge about ethics theories and methods for ethical analysis can be used for all kinds of ethical dilemmas, including those that are sustainability issues. The introduction of ethical dilemmas in education can thus be one way to simultaneously address sustainability issues and engineering ethics.

## Acknowledgements

We would like to acknowledge colleagues at Chalmers University of Technology who in different collaborations and dialogues have given us inspiration for the development of the framework that is suggested in this paper.

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# Teaching Social Sustainability in an Engineering Context

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## Abstract

At the KTH Royal Institute of Technology concerted efforts have been made in recent years to integrate sustainable development into the university's Bachelor's and Master's programmes. While a self-evaluation study conducted in 2012 revealed a significant degree of integration of ecological aspects of sustainable development into KTH's engineering education, teachers and programme coordinators expressed considerable confusion in how to approach the issue of social sustainability. The learning outcomes specified in the Swedish Higher Education Ordinance explicitly state that social aspects of sustainable development should be addressed in all engineering education in Sweden. However, a study conducted in 2013 showed that many of those who participated in the self-evaluation study believed that they did not have sufficient knowledge to address social sustainability issues to a satisfactory degree (Edvardsson Björnberg, Skogh & Strömberg, 2015). As a response to this, a course module on social sustainability, corresponding to 1.5 ECTS credits, was commissioned by KTH-Sustainability, the centralized organization for implementing sustainable development in education. The course module, which is available to all programmes at KTH, including Engineering, Architecture, Industrial Management and Urban Planning, was taught to around 150 first-cycle bachelor students in Mechanical Engineering in autumn 2015. This paper describes the development and implementation of the course module. The main focus of the module, which was developed by a group of teachers drawing competences from different knowledge areas such as social life-cycle assessment, ethics and political philosophy, motivational psychology, behavioral sciences and organizational development, has been to find ways of teaching social sustainability to engineers that make the topic appear relevant and urgent for them in their future occupations, i.e., to make the students identify the link between this topic, perhaps viewed by some as a 'soft' issue, and their engineering skills.

## 1 Introduction

Scientific and engineering advancements have consistently brought the world higher levels of well-being and led to increased production growth. This is truer than ever since the industrialisation in the middle of the 19th century. Since then many aspects of society and human life have experienced exponential growth. Engineers play an substantial role in the dissemination of the scientific advancements that have brought us the countless solutions that we take for granted.

For this reason it is necessary to provide students with the underlying principles that allow people understand and consider this topic. As engineers design such a multitude of solutions for people, it should be deemed as imperative to integrate and discuss principles of social sustainability in order to ensure that these solutions lead to fruitful societal outcomes.

An example of a highly successful, in terms of dissemination, technical solution is Facebook. Facebook has grown and reached a large user-base within a short period of time and is through an economic standpoint a success story. However, time spent on facebook has been linked to feelings of depression and anxiety due to social comparison (Steers, Wickman & Acitelli, 2014). In a german study of 584 people from 2013, one third of the respondents reported negative feelings associated to their facebook use. Furthermore they found that passive consumption of content on facebook exacerbates feelings of envy which negatively impact life satisfaction, and their study is not alone in their findings (Krasnova et al, 2011). Facebook has recently gained interest in behaviour and had a group dedicated to researching behaviour and impact on users, that until recently called themselves the "Trust Engineers" (Bejar, 2015).

Yet another reason for why knowledge of these principles is of importance is because they empower the individuals own self-leadership and they can inform team-leaders or managers as to what considerations are necessary in order to ensure a work environment is conducive to employee health and efficiency. The founding dean of Lassonde School of Engineering, Janusz Kozinski states that the most important factor to success as an engineer in today's globalized world is the ability to work in a team. Engineers work, despite potential prejudices, extensively with other people and often with leadership roles. An alumni report at the Royal Institute of Technology (KTH) from 2015, of alumni with 2 years working experience, showed that 48% of them had some form of leadership position at their place of work (KTH, 2015) and a 2006 study of USA's S&P 500 CEOs showed that 33% of them had engineering backgrounds (Spencer Stuart, 2006). These statistics are likely not unique for the United States or for Sweden but show that engineers commonly work with people and may even achieve positions where they have significant influence over other people's daily lives.

With greater knowledge of the principles of social sustainability engineers would be empowered to design and create solutions that deliver value more efficiently and contributes to more positive dynamics in society, as well as be empowered to improve their own leadership and self-leadership.

## 2 Development of the course module

### *2.1 Assignment goal and starting points*

The project goal was to achieve a 1.5 credit module (corresponding to one week, or 40 hours, of full-time studies) that concretizes the social aspect of sustainability to a broad engineering audience, that is to say that it should be generally applicable and relevant to all engineering disciplines. The starting point was a common definition within the group of the social aspect of sustainability. In literature, there is not one commonly agreed definition of the concept. However, in this project, the concept of social sustainability was agreed to represent the aim for a development towards a society "allowing all people to reach their full potential".

The development group of the module composed of a multi-disciplinary and diverse team, contributing with their own experience and theory, thus facilitating the process of identifying rich and diverse theories and aspects into a cohesive end-product.

### *2.2 Developing the Intended Learning Objectives*

#### *2.2.1 Constructive Alignment*

With the goal and definition set, the course module was designed using constructive alignment. Constructive alignment is an approach to course design which aligns teaching activities to the intended learning outcomes (Biggs and Tang, 2011). The underlying assumption is that learning is facilitated by selecting and organizing the teaching activities (instruction and examination) in such a way that they contribute to the achievement of a pre-determined set of intended learning outcomes, which are communicated to and ideally internalized by the students. Consequently, the next step in the development of the module was to agree upon and formulate a set of intended learning outcomes and deciding on ways to communicate them to the students.

In constructive alignment, the intended learning objectives should be formulated using verbs that clearly describe what the student should be able to do after having taken a course or a degree programme. Often, verbs are chosen that mirror different steps in a learning taxonomy, such as Bloom's SOLO taxonomy (1956). Four learning objectives were set for our social sustainability model. We developed them collaboratively and by using the above-mentioned principles:

1. *Explain* the concept of social sustainability in a global as well as local context, and the way it links to the ecological and economic perspectives of sustainable development.
2. *Discuss* of the concept of social sustainability from an equity perspective, including aspects of inter- and intra-generational distribution.
3. *Reflect* on the engineer's responsibility for sustainable development and give examples of how the engineer's work can affect people's ability to live a good life now and in the future.
4. *Describe* the array of decision-making tools available and discuss their applicability in various aspects of engineering work.

Outcomes 4 and 1 are on a basic level of the learning hierarchy, corresponding to Bloom's categories of "remembering", "understanding" and "applying". They involve basic propositional knowledge of sustainability terminology, facts, classifications and categories, tools, and general principles, as well as being able to identify and organize the three dimensions of the sustainability concept at different spatial and temporal scales. Outcomes 2 and 3 partly reflect learning on a higher level by including skills like being able to analyze various relationships, such as those between inter- and intra-generational distributive justice and between technological development and welfare generation, and synthesize the acquired knowledge by generating proposals for how to improve the social sustainability aspects of a selected technology or technological artefact (see section 3.3 below).The learning outcomes were included in the course memo and communicated to the students orally at the first lecture.

With the learning outcomes in place the team progressed to operationalize them based on the theory behind social sustainability and on pedagogy for learning complex subjects. The process was inevitably iterative, with learning outcomes having slight changes in wording and the operationalisation passing through different phases.

### *2.3 Developing the Course Contents*

Sustainable development – even when restricted to the social dimension – is a complex subject that involves many different aspects related to technology and technological development. Since our task was to develop a 1.5 credit module, a targeted selection of content had to be made. Our selection was based on a set of principles developed by Kember and McNaught (2007).

*Fundamental concepts*: The module was designed to help the students gain understanding of the key aspects of the social sustainability concept and how to implement "social sustainability thinking" in engineering practice, rather than covering the broad spectrum of issues falling under the umbrella of sustainable development education. In the first iteration of the module, the aspects being identified as fundamental to the social sustainability concept were: operationalisation of the social sustainability concept through a set of social boundaries (Raworth, 2012), which essentially express what resources or capabilities people need access to in order to live good, or fulfilling, lives; the necessity of looking to fundamental needs for human well-being, rather than cultural adaptations of those needs (Ekins & Max-Neef, 1992); and equity regarding the distribution of opportunities for welfare across spatial and temporal scales, as derived from the Brundtland definition.

*Relevance*: To ensure that the module felt relevant whilst still giving the entire picture of the concept the module was structured in two parts, one generic and one specific/tailored to the targeted audience group. Furthermore, we related the course contents to current sustainability issues (the newly adopted Sustainable Development Goals, poverty issues and the role of technology in furthering poverty relief, technology's role in enhancing social cohesion/inclusion, etc.) and real-life technical examples, both general and others that were more specific to a certain target audience (development of Fairphone, Hilti's hammer drill, etc...) whenever deemed appropriate.

*Meshing theory and practice*: Aside from using real-life examples from society and companies, the more specific part of the module contained a case-study (the examination), where the students chose a dynamic or product/service, related to their field of study, and analyze it from a social sustainability perspective with the help of certain tools that were taught in the module.

*Challenging beliefs*: Kember and McNaught (2007) argue that "if they are to get grips with fundamental concepts of a discipline challenging preconceptions is important". In our module, this was done through two learning activities: a seminar on the individual perspective of social sustainability and a role play focusing on the concept of justice (intra-/intergenerational, distributive/procedural, justice between humans and non-human animals). Both these activities were specifically designed so as to challenge the preconceptions that the students might have regarding happiness, human needs, equity and ethics.

### 2.4 Setting the Learning Activities

The module consists of two parts with learning activities within each of them. The first part is a generic part that looks similar regardless of where it is implemented, providing a foundation of knowledge in the subject. The second part is adapted to each implementation, and includes the main examination. Furthermore, it can be added a specific lecture (according to preference based on the students' specialization) to the second section that clarifies the link between social sustainability and program area. The generic part includes four activities: The first is an introduction to the subject and its relation to other aspects of sustainability (1 lecture). The second activity is a deep dive into what the personal social sustainability (1 lecture + 1 seminar), based on philosophy of happiness and the lesser known psychological needs of autonomy, competence and relatedness (Ryan, E. & Deci, R. 2006). The third activity problematizes the concept from a global perspective and a justice perspective (1 lecture + 1 seminar). The fourth activity gives tools for how to think about the issue and how the subject can be treated in a structured manner in the context of an engineer (1 lecture). The activities of the first part are also somewhat tailored to the target audience through the use of relevant examples and tools. The Tailored part of the module comprises one lecture and two seminars.

*Seminar on personal values:* Learning outcomes in the area of Social Sustainability are strongly based on the ability to reflect upon the concept and link it to daily practices. To a large extent the different views on Social Sustainability that exists are based on values. Therefore, it is necessary for the students to detect, discuss and reflect upon the values that are embedded in statements on Social Sustainability, and to find their own approach to it based on their own values. This seminar is designed to make the students reflect upon their values in a proven set-up.

*Role play:* A new role play was developed to facilitate achievement of learning outcome 2. Role plays can help students broaden their perspectives on issues and are powerful tools for "making the students aware of the different dimensions that frame a decision making process" (Doorn and

Kroesen, 2013, p. 1524). They have been used to teach sustainability and environmental issues to science and engineering students around the world, many times with promising results (Maier et al., 2007; Hoekstra, 2012).

Our role play took the form of a public hearing conducted by a fictitious *United Nations Council on Sustainable and Fair Trade* and focused on ethical issues related to natural resource extraction and waste management in the electronics sector in the imaginary country Baruba. The hearing was led by a board consisting of three students and followed a pre-set agenda with four items to be discussed: justice in an intergenerational perspective, global justice (today), public participation in decision-making concerning sustainability issues, and the social responsibility of the engineer. The role play lasted for two hours and was concluded by a teacher-led general discussion of the issues discussed during the hearing. Before the hearing the students were asked to read a collection of news articles related to the issues covered by the role play.

The module also wished to include a more active learning and experiential learning approach to help the students to connect with the material and gain further insights into its relevance. Active learning appears to improve the learning process amongst students (Segalàs, Ferrer-Balas & Mulder, 2010), (MacVaugh & Norton, 2011). A key element of the module to get a higher degree of active learning is to get theme social sustainability to be something abstract to something more concrete and connected to the student's own personal passions and values.

### *2.5 Examination forms*

The examination was designed as a short assignment aiming at the students to apply social sustainability in their own discipline, supported by the models and tools learnt within the course. Some of the intended learning outcomes (outcomes 2 and 3) was clearly aimed at deep learning (*reflect* and *discuss*). This relates to experiential learning and the related learning cycle (Kolb 2014) where the application of tools and model in their own field corresponds to build new knowledge by active experimentation , practising theories learnt in the abstract conceptualization step in the learning cycle.

## Implementing the Course Module – the Case in Södertälje

### *2.6 Starting Points and Prerequisites*

The mechanical engineering engineering bachelor at KTH Telge Campus (in Södertälje) accepted the course module in its entirety for both their second and third year students (a total of around 160 students) The module would be implemented in a particular course ("program-cohesive course") that runs over the entire three years of the program, and is built up by modules. None from the team had any previous experience with the target program or the dynamics and administrative requirements of a "program-cohesion course".

### *2.7 Adaptation of the Basic Layout*

The module was designed for flexibility and adaptability, as a consequence the structure was not modified dramatically. Certain aspects of the lectures were not designed in detail and were created for the module implementation.

The examination and tools were adapted to the program, along with certain success story-examples, in order to become more relevant to the field of mechanical engineering. Due to the large number of students, a peer-review process for the examination of the assignment, where the students gave feedback to each other in a group of fours students. Furthermore the role playing game's theme was well aligned with the material choice dilemma's of the target group. One support session, for the project that was given to the students as examination, was deemed superfluous for the target group and was removed. Aside from these changes the course was not modified.

### 2.8 The Outcome

The first implementation of the course module were deemed quite successful for the project group (also the teacher of the module). The module was also appreciated by many of the students with positive feedback such as (freely translated from Swedish):

- To be part of a course with new ideas and learn things that are emotionally important to us as people and colleagues
- Being able to speak out about things that you feel provides a good picture of oneself and others.
- It was interactive. Good combination of lectures and exercises.
- An experience to listen in to other people's thinking. To learn how others perceive the world.

Some learnings that the students' appreciated:

- That everyone has their own strengths and that we all are equal. That compassion for each other is important for a social sustainable future.
- Learned new ways to analyze sustainability issues.
- That there are no answers, only different complex issues.
- To better listen to and put myself in other people's narrative, and understand the other better.
- Finding myself and appreciate myself! Reflecting on the problems in the world and actually look for ways to solve them! To have a sustainable mindset
- I have learned about how social and environmentally sustainable development are interrelated.

Some areas that the students' wanted to learn more about:

- A deeper understanding of the tools and the concept. More concrete information and cases.
- How the various tools are used to analyze social sustainability. A deep-dive in system thinking.
- More about companies that are actually trying to contribute to a better world! As Fairphone etc., give some ideas on how we can embrace and initiate this way of thinking

Suggestions from students on improvement areas:

- The timeframe. It was too limited for me to feel involved in these big issues.
- More information about the tools, so as to have a better understanding when to write the analysis.
- Not having such a wide area. Social sustainability is quite large.

Some amendments, based on own experienced as well as the student feedback, will be done to the course module in the next round. Most importantly, the course assignments will be introduced in an earlier stage due to the short duration of the course module. By this, the students will be aware of on which problem they will apply the concepts, models and tools all along the course, and they can thereby follow the cycle from concrete experimentation and reflective observation (seminars and role play) to abstract conceptualisation (tools and models) and active experimentation (application, at least in their heads) for each step in the course module, instead of only doing active experimentation at the very end.

## 3 Discussion and Conclusions

The task of developing a course module for social sustainability for engineering students was a challenging one. Social Sustainability is an overarching, global and long-term concept. Therefore, the ability to link it to concrete action and apply it in specific areas is of great importance.

An important aspect of designing the learning activities is to consider the students; their background, pre-understanding of the subject, their motivation. In the case Social Sustainability, one tends to meet a lot of diversity. This is a topic that is by many considered 'soft' and unclear, perhaps in particular in the education of engineers, mostly trained in natural and technology science. This means that the pre-understanding of the engineering students in general is relatively limited. However, this is a topic that is widely covered in the media, and some students may have taken interest in the topic, developing a large engagement and pre-understanding. Also, this is a partly political issue; among the students there may be some that are firmly opposed to including this topic in the education of engineers. In order to get students to build knowledge in this area, the most important thing might be firstly to work with the pre-understanding, helping students to find links to the topic from their daily lives and present world views and handling cognitive conflicts and secondly to work with their motivation and engagement.

We have not used any diagnostics to get a picture of the level of knowledge and its spread. This is an area of improvement, to get a better view on the relative size of the group of student with substantial knowledge compared to the ones with very little knowledge. Also, it can be good to be aware of having one or several strong opponents in the group. To meet these individuals, it can be useful to start off by problematizing the topic and let them express their reservations and doubts, preferably in a peer-process with other students.

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# Dealing with societal challenges of a circular economy in engineering education

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## Abstract

On December 2nd, 2015 the European Commission published a new Circular Economy Package to stimulate Europe's transition towards a circular economy, aimed at boosting global competitiveness, fostering sustainable economic growth, decreasing carbon emissions, and generating 580,000 new jobs. The engineers educated today will be key role players in this ambitious plan. An important focus in circular economy education lies in aspects of resource efficiency, using less raw materials and energy, and innovative processes and products. Whereas this is a certainly challenging to stimulate the creativity, innovation, and entrepreneurial spirit of engineering students, social aspects of the circular economy perspective cannot be neglected and definitely deserve more attention.

Both producers and consumers play a role in the transition towards a circular economy. Although general public awareness about the circular economy will likely increase in the coming years, usability, acceptability, and user incentives are essential to design successful circular systems. It is here that engineers can play an important role, in engineering and designing their products so that they are accepted by the consumers. Besides the environmental impact of materials and products over their entire life cycle, social impacts (such as the social well-being of different actors and stakeholders in the value chain of a product), are receiving more and more attention. Social wellbeing is not only enhanced through resource efficiency improvements, but also by issues of societal concern, for example: job creation, labor conditions, transparent communication about a product (over its entire life cycle), etc.

In the present paper, we discuss some examples of how the societal impact of the circular economy concept can be addressed in courses and curricula in engineering education and beyond. Attention is paid to the role of life cycling thinking in adopting the circular economy concept, thus addressing environmental, economic, and social aspects. Examples also show the importance of taking into account consumer behaviour to analyse problems associated with human use of goods and services, within a circular economy framework  Finally, we illustrate some interesting examples on truly interdisciplinary (student) projects.

## 1 Introduction

The recently published Circular Economy Package (COM, 2015) aims to stimulate Europe's transition towards a circular economy, and engineers educated today will be key role players in this ambitious plan. An important focus in circular economy education lies in aspects of resource efficiency, using less raw materials and energy, and asking for innovative processes and products. Whereas this is a certainly challenging to stimulate the creativity, innovation, and entrepreneurial spirit of engineering students, social aspects of the circular economy perspective cannot be neglected and definitely deserve more attention. Engineers are trained to develop creative applications of science, with the aim to improve peoples' lives. Therefore, engineering education should also focus on raising the awareness for societal issues. Societal problems often determine what questions engineers tackle. Besides being experts in technology, they should also be trained to understand people, and to interact with people in such a way that they act as a mediator between people and technology. The technologies that are the products of engineering, as well as newly developed business models emerging from these innovations, influence society, not only by having an environmental impact, but they also affect human culture. The circular economy is about re-designing products to tackle planned obsolescence; moving from product to service thinking (the leasing or sharing economy); and re-designing supply chains, business models and organizations (ESCAP, 2014).

In the present paper we will first discus some ways to address social/societal issues of circular economy, within the framework of already existing course contents (i.e., Life Cycle Analysis (LCA) and sustainable design) of engineering curricula. We will also illustrate the importance of taking into account consumer behavior to analyze problems associated with human use of goods and services, within a circular economy framework Finally, we will elaborate on the role of interdisciplinarity and project-based learning, illustrated with some interesting examples on truly interdisciplinary (student) projects.

## 2 Addressing societal impact of circular economy

Methodologies, techniques, and tools have been developed for the sustainability assessment of product and process assessment, often to support policies and strategies for the social, economic, or the environmental dimension of sustainable development. Nowadays, life cycle thinking and LCA is being included in many engineering curricula focussing on process and product design. Although LCA classes are most often offered in engineering programs, it is increasingly taught in other fields, including chemistry, design, and architecture. The Environmental Product Declarations (EPD), a verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of a product, is an example of the practical application of LCA in the construction sector. The LCA methodology used for EPDs encourages using recycled material and for designing products that may be reused or recycled, thus steering towards products that are part of a circular economy. Nevertheless, LCA focusses on environmental aspects, not allowing a full sustainability assessment. In recent years, several efforts have been pursued to cover, in a more coherent and integrated way, all pillars of sustainable development, striving for a more holistic sustainability evaluation of goods and services.

### *2.1 Social life cycle assessment to complement environmental LCA and LCC*

Environmental impacts are much more frequently standardized and quantified than social and socio-economic ones (Dreyer *et al*., 2006). Because LCA focusses on assessing environmental impacts of goods and services, it is not uncommon that the interpretation of the results, and the recommendation drawn from the results, are in conflict with other interests in product such as economic or social considerations (e.g. labor conditions, intergenerational equity, etc.). The full sustainability assessment of goods and services can be performed through life cycle sustainability assessment (LCSA), combining three techniques: environmental LCA (E-LCA), life cycle costing (LCC), and social LCA (S-LCA). (Schau *et al*., 2012). Social LCA's can add an extra dimension to this environmental impact analysis. Because the whole life cycle of a product is taken into account, S-LCA results in a more holistic view on the social impact of product compared to other methods to evaluate social aspects (Jørgensen, 2013).

Despite the fact that methodology of S-LCA is still under development (Sala *et al.,* 2015), this framework could already be used in education to address societal issues of goods and services that are being developed within a circular economy concept. Because the basic steps of an LCA can also be adopted in S-LCA, S-LCA could find a place in engineering curricula in courses where ”traditional” LCA is addressed, even without going in-depth on all social aspects included in S-LCAs.

### *2.2 Sustainable design in higher education*

Ecodesign is the concept of taking environmental issues into consideration when designing and developing new products, or when updating existing products. Ecodesign focuses primarily on the environmental and economic dimensions of sustainable development, but does include aspects of the social dimension. Environmental and social impacts and management of resources from cradle to cradle are all important elements of the engineering context of sustainability (Boyle, 2004). Whereas ecodesign is considered a sub-discipline of sustainable design, ecodesign often also includes aspects of corporate social responsibility (i.e., healthy and safe working conditions, etc.), making the distinction between both terms not always very clear.

The Flanders' Materials Program combines ambitious long-term vision development, experimental pilot projects, policy-relevant research, and concrete priority actions in order to accelerate the transition to a circular economy. Sustainable design is one of the action domains of this program. Based on a screening of higher education for its potential impact on the design, service, and product launch, a list of opportunities and limitations concerning the integration of ecodesign in higher education in Flanders was made (Verhulst and Van Doorselaer, 2015). This knowledge was used to develop a tailored training package the, Ecodesign in Higher Education (EHE)-Kit, primarily developed for engineering courses (Verhulst and Van Doorselaer, 2015). It has been developed in and for the Flemish region (Belgium) but is now also available in English and can be applied in other countries and other disciplines, such as in management education. Since 2013, the Flemish design colleges have signed an agreement in which they commit themselves to incorporate sustainable design into their training.

## 3 Consumer acceptance and awareness

Whereas the benefits of the circular economy are more and more recognized, several barriers to the transition have been identified (European Commission, 2014), including limited consumer and business acceptance of potentially more efficient service-oriented business models, (e.g. leasing rather than owning), and shortfalls in consumer awareness.

Besides training engineers in basic and applied sciences, sustainable materials management, recycling methods, and life cycle assessment (LCA), they should also be trained to become key-persons in any industry facing the implementation of the circular economy concept. Making the transition to a circular economy asks for new skills across different disciplines. Although circular economy is strongly linked to the way materials are used and how products are designed, there are also important implications for changes in consumer behavior and business models.

### 3.1 Risk perception towards products emerging from circular economy.

Several interesting examples have been described in literature, showing that the acceptance of circular economy products and services by the general public should not be taken for granted. Refurbishment is the process of collecting a used product, assessing its condition, and replacing certain parts in order to resell the product to new consumers. From a circular economy perspective, refurbishment is identified as a promising design strategy to reduce the environmental impact of consumption goods, because it reduces waste and the use of scarce resources. However, refurbishment will only have a positive effect on society if it is widely applied and accepted in consumer goods. Van Weelden *et al.* (2016) explored consumer perceptions of refurbished mobile phones. The results suggest there are some important barriers to consumers choosing refurbished phones. The study showed that the people misunderstood what refurbishment means, associating refurbishment to second-hand, and believing that phones may be damaged and not fully functioning. Consumers felt purchasing a refurbished phone would not provide the same enjoyment as owning a new phone.

Another study on the use of dredged sediments as a resource for brick production (Cappuyns *et al.*, 2015) showed that consumers in Flanders are rather suspicious with respect to bricks produced from dredged sediments and their risk perception is mainly determined by the possibility of a bad bargain (brick of inferior quality) and the connotation with chemical contamination. While the risk perceived by a consumer can be based on the physical risk of using a product, there is typically a discrepancy between consumer and scientific risk evaluations. Besides personal characteristics, product characteristics also play a role in risk perception. In general, a higher risk is attributed to more complex products compared to ordinary ones with a lower (monetary) value (Mitchell, 1999). Sensitization and information of customers seems to be of primary importance to make this kind of products successful.

### 3.2 Acceptance of circular business models

Engineering education has evolved over the last decades from a purely technical education to an education including entrepreneurial skills in order to understand the context of market and business pressures. This entrepreneurship-focused education gives them solid experience in product design and development, prototyping, technology trends, and market analysis (Nelson and Byers 2010). Nowadays, engineering students are also trained to develop business models, commercialize new and existing products, and to transfer technology.

Based on a literature review, Van Eick (2015) concluded that, "*Circular Economy demands a system change with parallel actions along the value chain rather than a purely sector and/or product focused approach. This also requires institutional changes, cultural changes, technological innovation and knowledge development & exchange just as closer cooperation and transparency between all actors (governments, businesses, inhabitants and the science & education community).*"

Despite the fact that circular business models provide huge opportunities for companies, customers, and the environment, their benefits alone will not translate into widespread acceptance of the idea of circular economy business models. Besides rational motives, non-rational motives of consumer behavior have to be taken into account, including the habits and routines of individuals (Planing, 2016).

## 4 The circular economy as a subject of interdisciplinary student projects

Multiple aspects of circular economy can also be addressed in student projects in which students from different background work together. During interdisciplinary projects, the students become aware of their specific disciplinary contribution, they learn to communicate without using technical jargon, and discover their critical role towards persuasive information (Mulder, 2006). The success of a project does not only depend on individual performances, the capacity of the group to work as a team, is also a key factor of success.

We describe two interesting examples of interdisciplinary student projects, one on the international level, the other on the national (university) level, in which different key elements for a circular economy (ecodesign and sustainable resource management) are addressed, taking into account technical, environmental, economic, and social aspects.

### *4.1 European Project Semester (EPS)*

A European Project Semester (EPS) falls within the Erasmus student exchange program and provides international multidisciplinary project (e.g. in the field of industrial design) training in teams. EPS is a mixture of "project related courses" and project organized/problem based learning. Students work in international and preferably interdisciplinary teams of 3–6 students on their projects (e.g. Malheiro et al., 2015). Besides the project itself, credits are reserved for general subjects such as culture, language, team building, project management, and theory in support of the project. Ecodesign can be integrated within an EPS programme, (Verhulst *et al*. 2015) with projects that often provide an interesting starting point for a product-service combination. The *Univeristat Politéchnica de Catalunya* proposes an International Design Project Semester (IDPS), a one-semester course designed to train final-year industrial design engineering students to work in international teams.

### *4.2 Interdisciplinary assessment Project (IAP)*

The Interdisciplinary Assessment Project (IAP) is a course offered at KU Leuven (Belgium) , for students in Environmental Health and Safety management, Commercial Engineering, and Applied Engineering Sciences. This course gives students the opportunity to cooperate in interdisciplinary teams to resolve real-life cases of business problems. In these cases, economic, technical, and sustainability issues are brought together and resolved. The 2014 edition of the IAP focused on sustainable resource use and included projects of companies in the automobile, electronics, manufacturing, materials, and energy sectors. The winning project dealt with tools, technologies, and products for enhanced landfill mining (ELFM), an innovative new business concept to valorize materials and energy from abandoned landfill sites.

In this kind of projects, plenty of opportunities can be found to address the wider societal impact of circular economy, by including, for example, issues such as communication with stakeholders, external costs and benefits, etc. From the perspective of people living in the neighborhood of ELFM facilities, they are often seen as a potential threat to health, safety or prosperity. However, they often represent opportunities for business and society. Private investors typically do not take into account external benefits or costs to society, as these are not fully borne by the private investor (Van Passel *et al.,* 2013). Examples of beneficial effects of ELFM include lower environmental pollution, restoration of nature and biodiversity, and reduced import dependency. An investigation of local community participation in an enhanced landfill mining project (Sips et *al.,* 2013), showed that setting up a multi-actor platform, organizing a group of involved locals, and involving local people as bridge figures (combining formal and informal communication channels), etc. can tackle these problems.

## 5 Conclusion

The European Academies' Science Advisory Council (EASAC, 2015) reviewed the benefits foreseen for a circular economy and potential risks for the transition phase. Among others, lack of circular economy programs at all levels of education, and the lack of information/awareness (on alternative options and economic benefits) are considered important barriers in a transitions towards a circular economy.

Besides the environmental and economic benefits that are expected from a transition towards a circular economy, many societal challenges deserve the necessary attention. Whereas the focus in engineering education is still on technological and environmental aspects, several opportunities to address societal aspects of goods and services from a circular economy exit. The circular economy concept can be addressed in engineering education, even without specific circular economy programs or courses. S-LCA can be used to include social aspects of goods and services, within a life cycle perspective to complement environmental LCA and LCC. Social aspects inherently linked with circular economy goods and services are also addressed in courses on sustainable design, and consumer behavior, and their importance for engineering education should not be neglected.

Finally, interdisciplinary projects offer many opportunities, not only to acquire knowledge on the circular economy concept and its practical implementation, but also increase students' awareness of societal impact of the goods and services they develop. Moreover student develop soft skills (e.g. communication, stakeholder engagement, etc.) that are essential to make circular economy-based goods and services acceptable for the general public.

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# Sustainable Development and Accreditation of French Engineering Universities

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### Abstract

Many European Engineering Universities have not yet really taken into account the global Challenge of Sustainable Development. However, both in the field of ecology that in the field of societal management, engineers are certainly amongst the most concerned people. Three years ago, Commission des Titres d'Ingénieurs (CTI), which is the quality and accreditation agency for French Engineering Universities, decided to become an active partner to make institutions turn faster to SD. This agency has the specificity to be composed half of academic people, half of professional ones: the introduction of criteria linked to SD in the analysis of the quality of an institution is something fundamental as well from people coming from companies as from academic people.

In France, Loi de Grenelle is, from some years imperative for institutions, however it is not yet always followed; lobbying groups contribute more than the law to make change possible. CTI built its own position through a common action with those groups. In 2014, the reference book of CTI's criteria was modified to include criteria concerning SD. However in 2016, we need to stress that those modifications were not been completely understood, as well by institutions as by CTI's experts. So a new accreditation campaign has now been launched in February 2016 with specific "focuses" on SD that each concerned institution has to answer; they will be then analyzed and a feedback will be given to them.

The aim of this paper is to share CTI's approach from the premises to this final focuses so that we can discuss it with other European countries specialists and perhaps understand what make things go better or worse than elsewhere, due to the specific parity organization of CTI.

## 1 Introduction

### *1.1 Why is it so important*

All of us contribute to the future of our planet, but young people are furthermore important because they will have to imagine new solutions for the future of their own world. Considering things especially in Europe, some Engineering universities were very up to date on those fields (TU Delft, UPC Barcelona...) while other still wonder how to do. I was in a good position to observe this as the Responsible for SEFI (Société Européenne pour la Formation en Ingénierie) of the Working Group "Sustainability in Engineering Education".

The work we have to do to be more sustainable is global and all the Engineering Universities must be concerned in their own way to find local solutions to global problems, that means also that accreditation process has to be enough compliant to differences .

### 1.2 Engineering and SD

Engineering universities were very soon concerned by SD by it was on specific points concerning mostly their research, from 1986 (Brundtland declaration) activities linked with technology such as ecology, chemistry and energy began to be oriented to waste reduction, energy saving or reduction of pollution and teaching then followed: by the end of 90-s beginning of the 2000, some teachings for example about eco-design were introduced.

However, the first global teachings covering the 3 points of SD (Society, Economy and Ecology) inside engineering universities can be considered as realized in TU Delft in 2002 (Ferrer-Ballas, 2011). You can find a more detailed information on what happened from the Barcelona declaration to the surveys realized realised by "The Alliance for Global Sustainability" in (Jolly, 2016).

## 2 What is CTI and how it works

The Commission des Titres d 'Ingénieurs realizes, in a mandatory way, accreditation of Public and Private Engineering Universities in France and on request abroad. This agency is member of ENQA (European Network for Quality Assurance), this means that it satisfy some important prerequisite such as adapting its accreditation criteria to the evolution of society and demands of its stakeholders.

Social responsibility is considered in France as a heavy challenge for engineers, and moreover, besides CTI's criteria concerning technical skills, there are criteria that concern soft skills: in France accreditations human and social fields of teaching must represent about 25% at the least of the program.

Six years ago, the criteria concerning SD were not put in the mandatory ones, we had written a document called "Analysis and Prospective" which was available on our website to help institutions to orientate their evolution. Then, according to the process that will be described latter, they became part of the mandatory criteria (this norm is only strictly used when CTI accredits French Engineering Institutions).

### 2.1 A parity based organism

CTI has the particularity to be a parity based organisation (when it was created in 1934 it was already parity based), this means that, before all regulations concerning quality, missions of audit, leading to accreditations, were already conducted both by professional and academic members, these same members define and also make criteria evolve.

Very often, norms concerning SD were in application in companies (such as in chemistry for example), this made professional members very receptive to problems linked to the domain of SD.

Furthermore, the observation of the consequences of the non-respect of SD are observed in the society not only by people in research or education but also in everyday life, especially in companies.

### 2.2 Reference and orientations

The set of rules corresponding to accreditation criteria described in a document called References et Orientations (R et O), it evolves each four years taking into account the propositions of the stakeholders of CTI but more generally it follows general trends of French or European society because CTI, as a member of ENQA, has to take into account those evolutions.

The set of criteria that must be taken into account by the institutions at each time is published and publicly available on the web site of CTI commission (R et O, 2016).

## 3 The French attempts to make SD mandatory in engineering institutions

In France the problems concerning SD have been soon taken in account by students, as well as by organizations of deans such as Conférence des Grandes Ecoles (CGE) and by Ministries, some of them trying to act as positive lobby. CGE is still very active in this field, it has recently edited a guide of skills concerning SD and its reflection group is in charge of the French evolution of the Sustainable LItteracy Test (SULITE, 2016).

The Ministry of "Ecologie, Energie, Developpement Durable et Aménagement du Territoire" put in place surveys and questionnaires (MEEDDAT, 2008) in France in 2008, they identified more than 300 curricula in SD (60 general universities, 37 technical universities) and stressed on an interesting difference between, on one hand the general universities concerned by a theoretical and conceptual reflexion on governance and political strategy and on the other hand the technical universities that appeared to have a more pragmatic approach based on energy, resources and Eco design; this report schematically opposes a top down approach in general universities and a bottom up approach in technical universities. In those conditions it is sometimes difficult to work in a multidisciplinary way necessary for the development of SD. It was also a topic discussed with CDEFI (Conference of the French Deans of Engineering Universities).

The network of French students for SD (REFEDD, 2008) realised in 2007-2008 a survey among the students (15 000 of them gave their opinion about SD and SD education) in order to make propositions resulting from these statements and expectations. The outcome was that teaching of SD was either absent or very specialised in French education. The students expected more active pedagogies connected to the "real world".

One of their propositions was to make campuses exemplary and to define a minimal curriculum that should be taught to everybody. However, due to the autonomy of universities, it revealed very difficult for this group to make institutions evolve quickly. A first attempt to evolve faster has been the Green Plan, perhaps because it is based on a law but also because it includes many of the aspects considered in previous attempts in Europe. We will describe it more specifically because it is one fundament of CTI's process.

### *3.1 Green plan*

According to a French law, the Loi de Grenelle of 2009, the Higher Education Institutions have to elaborate a Green Plan which is a plan intended for sustainable development including environmental preoccupations but also social and economic ones. In 2012, 100 institutions (among them 40% are engineering education institutions, that is 40 on the 206 French Engineering Education Institutions) had initiated this process.

With this experience, we can the success of Plan Vert needs:

-the SD strategy to be elaborated

-the institution mission to dedicate a person responsible for the animation, the setting and the evaluation of the SD process; this person must have human and financial resources

A framework has been defined after promulgation of "Loi de Grenelle", it has been named Green Plan Reference system (Plan Vert, 2012): it is a toolbox helping to define a SD strategy, its steering and its self-evaluation.

5 dimensions are to be considered for elaboration of the "Plan Vert" of an institution:

Strategy and governance,

Teaching and education,

Research,

Environmental management

Social policy and territorial management

With a sharper view it appears to be a specific application of ISO 26000, with considerations of: accountability, transparency, ethical behaviour, respect of laws, recognition of the stakeholder's interests, consideration of international norms of behaviour, respect of human rights.

Communication about such a tool is quite demanding, and is realized amongst other ways by associations of deans and presidents of universities; it is difficult to imagine that institutions could have never heard of it.

Furthermore, for institutions that want to go further than this legal basis, many organizations develop labels (EMAS, QUESTE…), tests (SULITE) or other actions (Rouvrais, 2013).

## 4. Vision of CTI on SD

According to ENQA criteria (European Standards and Guidelines), quality agencies have to take into account their stakeholders for the evolution of their evaluation procedures and their strategy.

### *4.1 The Approach*

In CTI, this ENQA's criterion is fulfilled thanks to informal meetings with stakeholders that take place regularly on all topics linked to the heart of the evaluation. Inside engineering education institutions, many fields are currently in great evolution regarding learning outcomes as well as teaching strategies or innovation.

In December 2012, a meeting took place between CTI and CGE, the benefits of Green Plan Reference on institutions were discussed, and the positive outcomes for the institutions appeared clearly. At the conclusion of the meeting it was decided to write immediately a new CTI's prospective document based on the Green plan reference which is, in France, considered as the norm for the SD field in higher education.

This prospective document was submitted to the organizations of students and then, one year later, the accreditation criteria of CTI were amended since the student's organizations agreed on those proposals.

The idea to start from an existing reference (Green Plan) was intended by CTI not to penalize institutions having already begun their process towards SD, and because it was also a national standard for general universities.

### *4.2 The CTI requirements*

Usually criteria for French Engineering Institutions accreditation are amended only every 3 years, and consequently should have been launched in February 2015, but in February 2014, CTI, considering that teaching social responsibility to engineers was a critical aspect for society and a duty for engineering institutions, decided to include immediately SD not only in the intended learning outcomes as it was, but also in the description of the global policy of the institution: this was an important evolution of the accreditation criteria (CGE, 2014).

The strategic guidance note of the institution being evaluated should include the orientation chosen by the institution regarding SD and particularly quote the Green Plan that describes the institution's strategy, its implementation and evaluation. The strategic guidance note is an important part of the self-assessment report because the institution's administrative council votes it, and when this institution is part of a group of faculties the university council also votes it.

*A. General ones*

CTI wishes strongly that institutions really integrate SD through curricula in the education of engineers but also apply the principles of SD in their own management, working in an exemplary way.

When an institution is accredited or reaccredited, the implementation of Green Plan has to be explained within the quality process of the institution. CTI has quoted 8 dimensions of operational actions to be verified during the evaluation process (examples will be given at the end of the paper):

-strategy and governance

-social management and local integration

-environmental management

-research

-curricula

-documentation

-industrial rooting

-quality management and continuous improvement

CTI stresses that a specific innovative active pedagogy has to be put in place for SD, this pedagogy of action puts the engineering student in the situation of finding and building solutions to "real world" matters. CTI also specifies that the recruitment of students must guarantee diversity according to a policy concerning chances equity.

The way CTI makes SD mandatory is a bit similar to ISO with respect to EFQM: ISO 9000 does not mean excellence it only means that the minimum standard necessary level is reached. So we can say that CTI requires the minimum concerning SD, hoping that institutions will do better!

We observe that even if the items do not appear in the same hierarchy, the global considerations of CTI are the same as in other systems because all of them are somehow related to the ISO criteria regarding SD.

*B. Learning outcomes*

However, regarding the curricula, the major point of the accreditation audit is the observation by the experts of the expected learning outcomes that the graduates must have at the end of the curriculum. T

3 of them are in direct relation with SD:

- The capacity to take into account the stakes of relationships at work, of ethics, of safety and health in the work
- The capacity to take into account environmental challenges especially by application of principles of SD
- The capacity to take into account society's stakes and needs.

During the audit of programs, CTI's members have to check this conformity but also how these LO are really assessed.

### *4.3 Some Results*

The points developed by schools can reflect some local interest (if means of transport for example are part of the local Agenda 21 of the city then they become a specific point). They are also linked with the specific activity of the school (teaching and research in the fields of chemistry and thermal motors make the school more concerned on those points). Some schools decided to imply as many people as possible and the themes to be improved have been chosen by all of the employees (i.e. incitement and facilitation of the use of bicycles, reduction and waste sorting, teleworking, management of the car pool, biodiversity). In other one, a self-assessment is realised each year on the SD approach, or in another the Green plan is led by the students instead of the staff.

The first results were however not completely satisfactory, because very often either the dean of the school either the experts in charge of this audit did not really realize that criteria had changed or do not know how to act

### *4.4. Evolutions*

However, when the Self Evaluation Report of a faculty arrives at CTI's staff, if the Main Reporter in charge of the audit of the school advises the dean of this school that things are not as expected, the prospective elements that the school will use to put in place SD arrive very soon as a prospective document.

So as to face the inexperience of experts or even members, another meeting took place in CTI in the beginning of 2016, animated by people specialists of SD, discussing and explaining the motivations of SD to experts and members, and also the various forms it can take in education.

We decided to include also experts, specialist of SD, in the teams of audit so as to be sure to ask the good questions and thus help the school to put in place a strategy of development in the field of SD. It revealed to be very positive.

## 5 Focuses

### *5.1 The concept*

In February 2016, CTI decided to go further. Because some new points of view concerning engineering were out the traditional field of investigation of CTI, and because those points presented some difficulties, not only for school but also for experts, we decided to put in place what we call "Focus".

A focus is a specific point developed by the institution in 3 or 4 pages that will be delivered by the institution together with its Self-Evaluation Report. Each focus includes questions about a specific theme to which the school has to give its own response.

This year the societal implication of schools will be put in evidence through three different focuses:

-sustainable development

-health and safety at work

-innovation

The CTI, conscious of the work given to schools by these "focus", decided to submit each school evaluated in the year to only one of these 3 focuses. However a school who decide to write a specific focus on one or more of these is encouraged to do it. Our aim is also to collect best practices and then broadcast anonymously them to all the community: we know that the very different sizes of French institutions do not make easy the invention of practices, organizations and pedagogies and we think that the fact that one institution read what another one had imagined could be a good thing for all of them.

Each of the group of documents on a specific theme will be analyzed by an expert of this domain and a specific synthesis work will be realized: according to our expectations it could be 10 or more documents that lead to this synthesis. Then this synthesis will be broadcasted to all institutions: this communication will be done at the occasion of the annual conference of CTI where all the deans of French institutions are present.

Our aim is also to show that there is not only one road to progress to the objective.

The fact that CTI's consigns are a bit fuzzy is something that is perfectly wished because according to the fields of activity, of the historic situation, of the recruited students, the path followed by institutions could be significantly different. One very important point is not to stigmatize institutions: the communication on the report on focus will of course be anonymous concerning the institutions!

For the following years, as the CTI demarche is a pragmatic one, according the success on this first attempts, other focuses on main themes could be decided.

## *5.2 The focus on SD*

The specific focus on SD especially includes 3 fields of questions to institutions.

- The first questions concern the vision and engagements of the institution:

-how the vision of Societal Responsibility is visible in the management of the school and in the profile of graduates?

-by who and how are defined the key competences of the pedagogical program in this domain?

-how do the Learning Outcomes defined by CTI concerning SD appear in the pedagogic program?

-how the organisation and functioning of the school are in resonance with the skills aimed for graduates?

- The second group of questions concerns the programs and pedagogic methods:

-has a specific pedagogic device dedicated to systemic societal questions been put in place in the first year in the school?

-are the great challenges of society (resources, climate, energy, biodiversity, health...) integrated in the teaching units of the other years? With which volume, with which pedagogy?

-are there projects corresponding to the notion of societal responsibility?

-are there associations of students operating in this domain?

-does the specifications of periods inside companies (internship, missions) include a work of the students on those fields?

- The third point concerns assessment of those skills:

-are the students evaluated on SD?

-during which activities?

-are the students submitted to the SUlite test?

-how the skills assessed are presented in the global skill matrix?

The documents on SD will arrive to CTI on June 15th and July 15th so we will have a first idea of the success and conclusions of this focus.

## 6 Conclusion

CTI is really wishing to make SD at the heart of the pedagogic process of engineer's education in France.

From 2012, the attempts have been very pragmatic, because we want as for quality management that things really come from institutions, including in the process all their stakeholders.

There is not one unique demarche for this process for all institutions and that is why CTI wants to have a global idea of the evolution of things along the time in different kind of institutions: we really hope that focuses will help both institutions and CTI to best manage SD.

In parallel CTI goes on with its participation with other French groups on SD research: for example, it participated in the works of the group of CPU-CGE concerning skills.

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# Sustainability assessment of higher education curricula: a critical reflection

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## Abstract

While a curricula assessment can offer university leaders a starting point for change, the approach to such an assessment can widely impact the results. The varying conceptualizations of "sustainability", and what can be included under this umbrella term, only adds to the complexity when discussing methods to assess whether curricula can be labelled as "sustainable". This article examines the varying results of two different assessment approaches: 1) an ECTS file scan for sustainability-related terminology, and 2) the use of a holistic context-specific course file. While relying on overview files (such as ECTS) to assess the sustainability of curricula is a common method, this can be a limiting approach because of: 1) instructors ' lack of intrinsic linking of their course to sustainability-related themes, and 2) assessor biases/inability to fully understand the course based on the limited content of ECTS files. The broadness of sustainability-related themes included in the self-assessment better captures the horizontal integration of sustainability into curricula, and the conceptualization of "sustainability" during the assessment impacts the extent to which sustainability is perceived as being integrated in the curricula. For the context of engineering education, critical reflection on assessment approaches is important, as assessment methods could help broaden conceptualizations of sustainability to go beyond the traditional inclusion of environmental topics in engineering education.

## 1 Introduction

The integration of sustainable development (SD) has become a relevant topic in higher education, and increasingly, higher education institutions (HEIs) are attempting to take responsibility as agents in promoting SD principles (Lukman and Glavič, 2006). SD competencies, that ensure HEIs are preparing students for the complex and uncertain context of sustainability issues (e.g., Rieckmann, 2012), clarify the broad and blurry concept of education for sustainable development (ESD) and enable educators to integrate ESD in their study program. There is a general acceptance that competencies for SD require new approaches in teaching and learning (Tilbury and Mulà, 2011), and a reorientation of education is needed towards more multi-, inter-, and transdisciplinarity, self-regulated learning, project- and problem-based learning (Lambrechts et al., 2013). This transition is characterized by: 1) interactive and participative methods, 2) action-oriented methods, and 3) research-based method (Lambrechts et al., 2009, 2013). In regards to the integration of SD into higher education (HE) curricula. The integration of sustainability into curricula can be done vertically (sustainability integrated in an explicit way via specific sustainability-related courses) or horizontally (sustainability integrated implicitly within different regular courses of the curriculum) (Ceulemans *et al.*, 2011; Lambrechts *et al.*, 2013; Figueiró and Raufflet, 2015). However, an often-cited barrier to SD integration is the "my-course-doesn't-have-to-do-with-sustainability" attitude instructors can adopt (Ceulemans and De Prins, 2010; Ryan and Tilbury, 2013 2004).

Despite higher education's essential role in contributing to a sustainable society, the conceptualization of "sustainability" and its intended manifestation in HEIs differs greatly among stakeholders (Wright, 2010; Sylvestre *et al*., 2014); with objectivists taking the stance that something can be labelled "sustainable", countered by the subjectivists calling for an approach in which "sustainability" is a construct that is in the process of perpetual (re)creation. The roots of ESD have been credited in the environmental education movement beginning in the 1970s (Monroe, 2012). Although the current paradigm for sustainability in HE calls for a holistic integration of economic, social, and environmental concerns, the historic roots in environmentalism creates a tendency to resort back to environmental-focused rhetoric (Lindstone *et al.*, 2014).

While environmental-sustainability themes are relevant in engineering (i.e., resource efficiency), engineers are trained to develop creative applications of science, with the aim of improving peoples' lives. It is vital that the integration of sustainability into engineering education transcends environmental sustainability and includes focus on raising awareness for societal issues. Ashford (2004) called for a multi-dimensional conceptualization of SD for engineering education, placing technological innovation as the primary driver of SD solutions. Management and entrepreneurship have been introduced in the engineering curriculum over the last decade (Karim, 2016), so graduates can transform technological innovation into real-life sustainable business applications (Momete, 2015). Despite the need for a holistic conceptualization of sustainability in engineering education, Boks and Diehl (2006) noted that when integrating sustainability into engineering education, students as well as staff tend to revert to their own definitions and perceptions of sustainability (even when provided with broad definitions), and these perceptions emphasized environmental sustainability.

Lozano and Young (2013) stated that a curricular assessment can offer university leaders a starting point for change. However, the conceptualization challenge complicates assessment methods. The very notion of "sustainability" is constantly evolving, what constitutes ESD is also constantly in flux, whereas an assessment requires the ability to qualify what is being assessed. Tools to assess the integration of SD in higher education, include (but are not limited to): the Auditing Instrument for Sustainability in Higher Education – AISHE (Roorda, 2001), the Graphical Assessment of Sustainability in Universities – GASU (Lozano, 2006), and the Sustainability Tracking, Assessment & Rating System – STARS (AASHE, 2016). Saadatian *et al*. (2011) evaluated 18 sustainable higher education assessment tools from 1998-2011, and they concluded that STARS was one of the strongest assessment approaches based on its novelty, comprehensiveness, and popularity (Saadatian *et al*., 2011). STARS, developed by the Association for the Advancement of Sustainability in Higher Education (AASHE), is a self-reporting framework intended to help HEIs track and measure their sustainability progress using a set of measurements (credits) (AASHE, 2016). STARS Credit AC 1 deals specifically with the course content. The STARS Technical Manual calls on institutions to conduct an inventory of 1) "sustainability courses" (courses for which the primary and explicit focus is on sustainability and/or understanding or solving one or more major sustainability challenge), and 2) "courses that include sustainability" (courses that are focused on a topic other than sustainability, but incorporate a unit or module on sustainability or a sustainability challenge, include one or more sustainability-focused activities, or integrate sustainability issues throughout the course) (AASHE, 2016: 31). The STARS guidelines state, "Each institution is free to choose a methodology to identify sustainability courses that is most appropriate given its unique circumstances (AASHE, 2016: 34).

Even with the presence of varying tools, approaches to assessments of sustainability integration in curricula have been contested in literature (Shriberg, 2002; Lambrechts and Ceulemans, 2013). Within existing tools, there are still relatively few indicators concerning course content (Yarime and Tanaka, 2012). While Glover (2011) explored validity issues of the STAUNCH tool, Karatzoglou (2013) found that ESD literature exploring measurement issues is still weak (Karatzoglou, 2013), and Ceulemans *et al* (2015) called for further research on implementation and validity of sustainability assessment tools. Using the STARS AC1 Credit as a framework, this paper contributes to discussions on ESD assessment by examining the effects of different methods in evaluating the integration of sustainability in curricula. Figueiró and Raufflet (2015) noted that authors in the field of sustainability in management education tend to be practitioners in the field and are often "agents of change" in their own organization, thus explaining the reflexive role of literature in this field. As the main author of the current paper is the Sustainability Coordinator of the KU Leuven Faculty of Economics and Business (FEB), exploring the outcomes and implications of assessments of a FEB program can be seen as action research conducted by and for those actors undertaking the action and aimed at both theorizing about and improving certain practices (Jupp, 2012; McTaggart, 1991). Thus, this research aims to both improve assessment methods internally for the faculty, as well as contribute insights to literature about how varying methods can impact assessment results. This research fits into Stephens' (2010) proposed research framework for SD in HEIs as a reflexive activity—offering the experiences of curricula assessment at the KU Leuven university Faculty of Economics and Business—as well as prescriptive—highlighting the need for attention to be paid to the conceptualization of sustainability and methodological approach chosen for curricula assessments. Therefore, the contributions made in this paper are valuable for the implementation of SD in disciplines other than economics and management, including engineering education.

## 2 Methods

The KU Leuven Master of International Business Economics and Management (MIBEM) program will be used as a case study to reflect on different methodologies of applying the STARS tool to assess sustainability in curricula. As the STARS guidelines do not include specific instructions as to how to map "sustainability" in curricula, two methods of curricula mapping will be used: 1) a terminology scan of ECTS files and 2) an analysis of course files. The results of these two methods will be compared and the strengths and weaknesses of these two approaches will be discussed. In addition to the relevance of business and managerial education to engineering education as discussed above, the STARS tool is meant for sustainability assessment of any HE program. Therefore, the lessons learned from assessment approaches in this research can also be applied to assessment any other program, including engineering programs.

The KU Leuven Master of International Business Economics and Management (MIBEM) program is a one-year master's program (with a six-month preparatory track of eight courses) that prepares students for a career in the international business world by developing students' (business) economic acumen, knowledge, and management skills. The KU Leuven uses the European Credit Transfer and Accumulation System (ECTS), that includes information describing the course, its learning outcomes and credits, as well as evaluation methods and grading schemes. In academic year 2013-2014, the MIBEM program head developed a holistic course file template. In addition to describing the course content, learning outcomes, credits, and evaluation found in traditional ECTS files, the course file includes information about how the course fits into the overall program, teaching methods, and other supplementary information. In an attempt to gain a more in-depth perspective of how sustainability is integrated into the MIBEM program, the following aspects of sustainability were integrated into the course file by the faculty's sustainability coordinator, in collaboration with the faculty's corporate social responsibility (CSR) professors: 1) sustainability competencies (Rieckmann, 2012) (holistic in nature and aim to re-orientate education); 2) pedagogical approaches (have an impact on the degree to which students gain competencies for ESD); and 3) themes related to ethics, responsibility, and sustainability (for instructors to link the content of their course to). While a course file can be used during the assessment of ESD competences and pedagogies, the current research will only address with the potential of a course file to assess the presence of sustainability themes in course content.

The first, and commonly used, method for curriculum assessment is a scan of ECTS files (Ceulemans *et al.*, 2011; Lozano, 2010; Mälkki *et al.,* 2015). The ECTS files of all courses (preparatory, compulsory, and elective) included in the MIBEM 2013-2014 program were screened for the presence of sustainability themes, first, using limited terminology, then expanded to be more holistic. The authors have chosen to use the following terms to verify the explicit presence of sustainability in the MIBEM program: 1) sustainability (*sustainability*, *sustainable development*), 2) corporate social responsibility (*responsibility*, *corporate social responsibility*, *CSR*), and 3) ethics (*ethic(s)*, *ethical*). Based on preliminary reviews of ECTS files, terminology was further expanded to encompass additional sustainability-related terms harvested from the ECTS files themselves, organized into additional SD-related themed: 4) stakeholder inclusiveness (*stakeholder*); 5) market failure (*market failure*, *externalities*, *common resources*); 6) environment-related terms (*ecology*, *environment*, *planet*, *green*); and 7) society-related terms (*socio-economic*, *society*, *social welfare*, *human rights*, *labor* [in the context of labor rights], *[un]employment*, *[in]equality*, *diversity*).

The second method for assessment is a review of course file content. The course files include explicit checkboxes for different sustainability themes (n =34). Instructors are therefore able to "self-assess" and link the content of their course to any and all of the 34 sustainability themes included in the course file.

The courses "Research Proposal Master Thesis" and "Master Thesis MIBEM" have been excluded from the research, as these courses are meant to guide students in the development of their individual master theses and are not structured in a way that makes their content comparable to other courses. Three course instructors failed to complete a course file, thus three courses were not self-assessed by their instructors based on the course files. Therefore, of the 26 courses of the program, 24 are included in the ECTS scan and 21 are included in the course file analysis.

## 3 Results

The assessment method chosen affects how well sustainability appears to be represented in a given program. Out of 24 courses included in the ECTS scan, 8 courses could be labelled as "courses that integrate sustainability" when using the initial terms, and 13 courses could be labelled as such when using the expanded terminology (33% and 54%, respectively; see Figure 1). When asked explicitly if their course deals with specific sustainability themes in the course file, instructors were more inclined to link their course to sustainability. Of the 21 courses included in the assessment, 19 courses could be labelled as "courses that include sustainability" (90% of courses).

Even within the confines of one theme, instructors are more inclined to link their course to a theme of sustainability when asked explicitly. Based on the results of the course file, ethics is report to be present in 6 courses (29%), compared to just 2 courses (8%) if relying solely on an ECTS scan.

Figure 1 illustrates the extent to which a course is "saturated" with sustainability themes. Interestingly enough, the course *International Economics* addresses the most sustainability themes—25 themes based on the results of the course file—while the course Corporate Social Responsibility "only" addresses 15.

When examining the sustainability themes most prominent in the curricula based on the ECTS scan (see Figure 2): 3 courses integrate sustainability (12.5%), 3 courses integrate responsibility (12.5%), 2 courses integrate ethics (8.3%), 6 courses integrate environmental themes (25%), 3 courses integrate stakeholder inclusiveness (12.5%), 3 courses integrate market failure (12.5%), and 9 courses integrated societal themes (37.5%). Of the sustainability-related themes in the course file, the most prominent theme in MIBEM curricula is "social value creation", with 12 courses integrating this theme (57.1%). Thus, regardless of approach, society-related themes are the most prevalent in the MIBEM program.

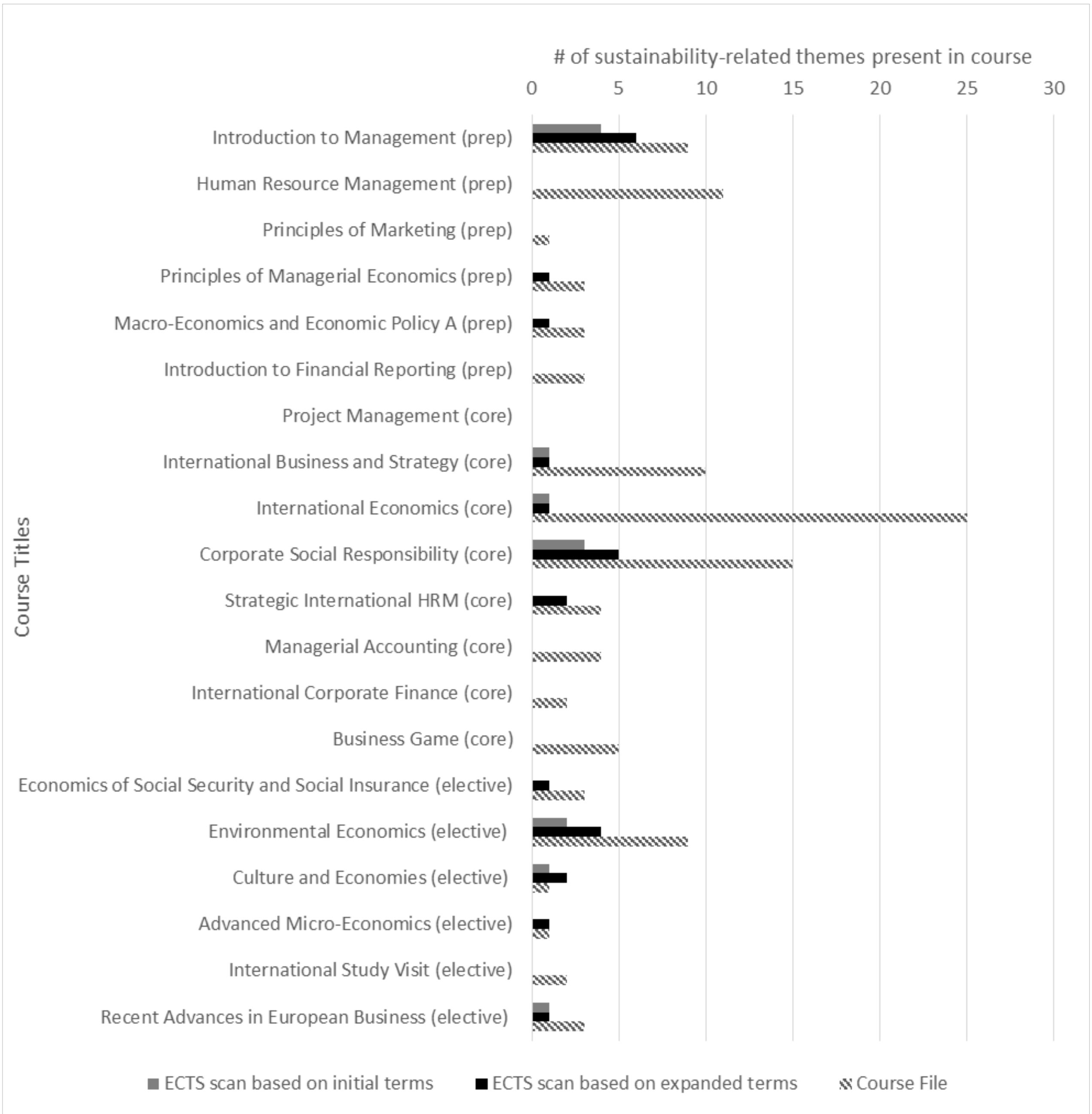


Figure 1: Saturation of sustainability themes in KU Leuven MIBEM courses.

## 4 Discussion

The use of a course file can help assessors to holistically capture the extent to which sustainability is integrated into curricula. This approach of teacher-lead assessments removes the middleman of external assessors as seen in previous literature on curricula assessment (Ceulemans *et al.*, 2011; Mälkki *et al.*, 2015). As noted in Mälkki *et al.* (2015) when describing their approach, “The scarce and limited descriptions of the learning outcomes do not always show the real situation in teaching” (Mälkki *et al.*, 2015: 242). Similarly, in the case at hand, the ECTS files ranged in terms of the depth of their description of the course, which makes them less preferable tools for assessment. Even when ECTS are holistic in their description, they are meant to be brief overview files and therefore not every aspect of the course content is included. A checklist of themes related to sustainability allows instructors to readily link their course to sustainability. As seen from the case, when instructors are given the opportunity to link their case to specific sustainability themes (e.g., ethics), there appears to be more sustainability themes present in the curricula. This can help instructors conceptualize sustainability in a broader sense and overcome the mentality that their course does not deal with sustainability. By having instructors self-assess, the potential for assessor bias (i.e., "external" assessor not fully understanding the course content based on the limited content of ECTS files) is also mitigated.

Regardless of the approach used, two trends emerge: 1) the broadness of sustainability-related themes included in the assessment better captures the horizontal presence of sustainability into curricula, and 2) the conceptualization of "sustainability" during the assessment impacts the extent to which sustainability is perceived as being represented in the curricula. While a relatively intuitive notion—that increased terminology yields increased inclusion—the process of re-examining the terminology based on the contents of the ECTS files forces the re-conceptualization of sustainability as it exists in the specific context of a program, faculty, domain, etc. "Sustainability courses" (explicit integration) can be catalogued relatively more straight forwardly in a objectivist manner, but "courses on sustainability" (implicit integration) require a subjectivist approach, in which "sustainability" is a construct that is in the process of perpetual (re)creation. An assessment requires the ability to qualify what is being assessed, and as this is in perpetual metamorphose, the assessment itself proves to be a challenging task with results that can vary greatly. Based on the results of both assessment methods, the social elements of sustainability are strongly integrated in the MIBEM program. Understanding the contribution of a specific program to the concept of "sustainability" can help to better formulate the context-specific conceptualization of "sustainability".

A context-specific conceptualization of sustainability may lead to more successful integration efforts. For engineering education, it is vital that the integration of sustainability transcends environmental sustainability and includes focus on raising awareness for societal issues. This can be limited by individuals' perceptions of sustainability that emphasizes environmental sustainability (Boks and Diehl, 2006). Therefore, constructing a holistic base conceptualization of sustainability during assessments that explicitly lists social and economic themes, and allowing instructors to self-assess, may lead to a process where engineering instructors are sensitized and themselves conceptualize sustainability in a more holistic sense.

There are limitations applicable to both approaches. The *presence* of sustainability-related content in a program does not necessarily mean integration of ESD in that program. The presence of sustainability themes in course content does not signify the relevance, extent, or effectiveness of the teaching (input), the weight and time given to these themes, or outputs (such as learning outcomes, or impacts in the long run). For example, one could be tempted to draw the conclusion from the case that sustainability is more integrated in the course *International Economics* than in the course *Corporate Social Responsibility* or *Environmental Economics* because of the high saturation of sustainability topics present in the course content as there is no reference to the weight of sustainability topics in the courses. Additionally, while the results of the assessment can serve as a starting point for mapping sustainability pathways in the curriculum, neither assessment methods explicitly measures the inter- or transdisciplinarity of sustainability integration as called for by Lambrechts et al. (2013).

## 5 Conclusion

While a curriculum assessment can offer university leaders a starting point for change, the approach to such an assessment can widely impact the results. The varying conceptualizations of "sustainability", and what can be included under this umbrella term, only adds to the complexity when discussing methods to assess whether activities (i.e., curricula) can be labelled as "sustainable". While relying on course overview files (such as ECTS) to assess the sustainability of curricula is a common method for HEIs, this can be a limiting approach because of: 1) instructors' lack of intrinsic linking of their course to sustainability-related themes, and 2) assessor biases/inability to fully understand the course based on the limited content of ECTS files. Giving instructors the ability to explicitly link their course to sustainability themes might also act as a method of sensitization for educators—helping them overcome the barrier of “my course doesn’t have to do with sustainability”. Regardless of approach, this research has shown that the broadness of sustainability-related themes included in the assessment better captures the horizontal integration of sustainability into curricula, and the conceptualization of “sustainability” during the assessment impacts the extent to which sustainability is perceived as being integrated in the curricula. The use of a course file can be a way to broaden conceptualizations of sustainability in engineering programs and achieve more holistic assessments.

The current research addresses some issues of popular approaches to ESD curricular assessments and highlights the potential of teacher self-assessment, but it is limited in that it narrowly focuses on the *presence* of sustainability themes in course content, while ESD encompasses much more (competencies, pedagogies, inter- and transdisciplinary education pathways, etc.). Further research is needed to explore how these ESD assessment tools are utilized and the usefulness of assessment results (comparability, assessor bias, etc.).

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# A Sustainability Retrofit of Engineering Undergraduate Education – Phase 2

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**Abstract**

Engineering undergraduate programmes in every continent are being retrofitted to include sustainability. Like many other engineering schools, the first year program at the University of British Columbia (UBC) has recently been redeveloped to align with design-oriented learning outcomes. Sustainability is an important component of the new program.

An earlier paper (Salvatore et al., 2015) reported on the first stage of the sustainability retrofit project of the UBC engineering undergraduate curriculum, which included an engagement process, first year engineering student responses to an informal survey, and recommendations for advancing the development of sustainability learning within the first year curriculum. In addition to presenting the theoretical frameworks that guide the retrofit project, this paper presents the results of deploying the recommendations of Salvatore et al..

## 1 Introduction

### *1.1 Curriculum Development of First Year Engineering Education for Sustainability*

First year engineering design courses have been shown to improve the intellectual development of students (Marra et al, 2000). Embedding sustainability learning into small group design experiences can leverage the educational advantages of these courses. For example, small group learning, like that found in design experiences, is associated with a greater commitment to completing a task, and more favourable attitudes relating to the subject and learning experiences (Springer et al, 1999).

Currently, reform in support of first year sustainability learning is viewed within a larger, systems approach to engineering curriculum renewal (Hayden et al., 2011, Rose et al., 2015). As part of the systems approach, it may be that incorporating sustainability into several courses across a curriculum is more effective than adding a multi-year series of sustainability-specific courses into an otherwise unchanged curriculum (Barella and Watson, 2015).

### *1.2 Cognitive Development and Sustainability Education*

The outcome based assessment of graduate attributes in engineering education, required by all accredited programs within signatory countries of the Washington Accord, requires engineering schools to indicate competencies toward appropriate outcomes through various assessment methods. Besterfield-Sacre et al. (1998) propose methods to assess student attitudes for program evaluation and improvement. The attitudes that students develop during their engineering education at a university will directly affect their ability to place the engineering knowledge in the context of society, and their attitude for life-long learning, which is reflective of the students' cognitive development. Battaglini and Schenkat (1987) applied the Perry and Toulmin models to cognitive develop of college students, where many start off as dualists. Understanding that students are required to develop in their meta cognition through their academic study, can guide the way in which teaching and learning occurs at a university. In cultivating critical thinking through understanding of cognitive development in students, Thoma (1993) used the Perry framework and introduced the Nelson variant to guide transitions of students' development. Nelson's variant of the Perry scheme indicates four modes through three transitions as listed in Table 1.

Table 1: Nelson's Variant of the Perry Scheme (adapted from Thoma, 1993)

| Modes | Transitions |
|---|---|
| Mode 1: Dualism | Transition 1: Uncertainty and ambiguity |
| Mode 2: Multiplicity | Transition 2: Opinion as insufficient |
| Mode 3: Contextual Relativism | Transition 3: Joining values and analysis |
| Mode 4: Contextually Appropriate Decisions | |

Sustainable development represents uncertainty and ambiguity. If engineering students are to develop skills to respond to the global challenges, the ability to understand their knowledge in the context of society, the environment and economic and industrial development, becomes critical. Huntzinger et al. (2007) assert that five attributes described by Felder and Brent (2004) can be skills needed by professionals for sustainable development:

1. possess the scepticism and inclination to challenge what is currently known;
2. question the assumptions underlying all accepted wisdom;
3. are reluctant to accept the first reasonable explanation;
4. employ both logic and intuition; and
5. avoid transferring judgments made in one situation to another situation without critical evaluation.

This paper describes first year engineering curriculum development activities currently underway within the University of British Columbia's (UBC's) Faculty of Applied Science, where sustainability is being integrated into two broad design courses. The paper also presents initial results from action research associated with the curriculum development, and reports the authors' interpretation of these results.

## 2 The UBC Engineering Curriculum Retrofit for Sustainability

The University of British Columbia (UBC) offers a common first year engineering program to approximately 850 students annually. In 2014, one of the authors of this paper embarked on the redevelopment of UBC's first year engineering program in order to improve the student experience of engineering design, and to introduce new students to concepts of professionalism, including ethics, communication, and sustainability. A key aspect of the redevelopment work, was to embed active learning into every aspect of the new program.

The results of the redevelopment work are two new consecutive courses in which students engage in structured team-oriented active learning. Each week, students first watch a short (8 to 12 minute) video and complete an on-line assignment. They then attend a 50-minute active learning class where they are team-tested for comprehension of the on-line material, and then engage in team-focused questions and discussions, as well as mini-lectures. The student teams next attend a 110-minute engineering studio during which the teams work together on a variety of projects and activities. Finally, the week is concluded with a 2$^{nd}$ 50-minute class, during which students, again, listen to mini-lectures and engage further in team-focused questions. Further details are documented elsewhere (Ostafichuk et al., 2016).

Six of the twenty-six course weeks are devoted to students developing sustainability knowledge, skills, and attitudes.

## *2.1 Advice from the 2014 Sustainability Roundtable Discussion Participants*

Potential learning outcomes and guiding ideas for the sustainability learning modules in the new first year courses, suggested during a 2014 roundtable discussion convened with faculty, students, and staff from across UBC's engineering programs, are incorporated into these six weeks of sustainability learning (Salvatore et al., 2015). A summary of this guiding material is provided in Table 2.

Table 2: High-Level Learning Goals Identified during the 2014 Sustainability Roundtable Discussion

| **Possible Sustainability Learning Outcomes for First Year Engineering Students** |
|---|
| Demonstrate an awareness of issues related to sustainability when considering real-world engineering problems |
| Articulate the context of an engineering problems in terms of sustainability and identify areas of impact (including identifying all stakeholders) |
| Describe the foundational concepts in sustainability (e.g. systems thinking) and demonstrate a working understanding of a sustainability lexicon |
| Think critically to apply concepts from sustainability to real world problems; ask the right questions |
| **Sustainability Suggestions for the First Year Program** |
| Integrate sustainability throughout the curriculum |
| Use case studies, possibly involving engineering failures, possibly involving a large number (~50) of vignettes spread throughout in-class and out-of-class activities |
| Focus on raising student awareness |
| Will need to consider how to educate instructors about sustainability |
| Highschool students are already exposed to sustainability so good to find out what students know about sustainability when they start the first year program |
| Note: consider highlighting novice to expert development and approach to dealing with complex, fuzzy, problems |

### 2.2 Curriculum Development

With guidance from participants in the sustainability roundtable discussions, the curriculum development team met over the summer of 2015 to develop the course-level sustainability learning outcomes, and then weekly from October 2015 to March 2016 to develop the detailed learning objectives, learning activities, and learning assessments to be included in the course weeks when sustainability was the focus. A list of the sustainability course-level learning outcomes generated from this process is provided in Table 3. A similar process of curriculum development was employed for the rest of the 7 modules in the first year courses (Ostafichuk et al., 2016).

Table 3: First Year Course-Level Learning Outcomes for Engineering for Sustainability

| APSC 100 – Term 1 | APSC 101 – Term 2 |
|---|---|
| Demonstrate an understanding of the definition of sustainability and the drivers of sustainability | Understand the definition of sustainability and the drivers of sustainability |
| Demonstrate an awareness of issues related to sustainability when considering real-world engineering problems | Be aware of issues related to sustainability when considering real-world engineering problems |
| Articulate the context of an engineering problem in terms of sustainability and identify areas of impact (including identifying all stakeholders) | Articulate the context of an engineering problem in terms of sustainability and identify areas of impact (including identifying all stakeholders) |
| Think critically to apply concepts from sustainability to real world problems; ask the right questions | Describe the foundational concepts in sustainability (e.g. systems thinking) and demonstrate a working understanding of a sustainability lexicon |
| Identify the significant issues to be considered when addressing a practical (complex) engineering question or task; Identify relevant known information, uncertainties, and biases, and key issues requiring investigation | Think Critically to apply concepts from sustainability to real world problems; ask the right questions |
| Demonstrate an awareness of issues related to sustainability when considering real-world engineering problems | |

The course developers and instructors are curious about the influence of the sustainability modules on the performance of first year the students and also on their "take-away" perceptions of sustainability.

## 3 Research Questions

As part of the action research surrounding the development of the new first year sustainability modules, we, the authors of this paper, have articulated guiding questions. They are:

- How well did the first year students achieve the sustainability learning goals suggested through the engagement processes?
- What were the barriers for students in achieving the sustainability learning goals?
- What is next step in the development of undergraduate engineering for sustainability curricula?

We share the expectation that investigating these questions will help us improve the courses over the long-term and may aid other who are considering curriculum development for sustainability education in undergraduate engineering programs.

## 4 Methodology

To address our research questions we collected two types of data.

### *4.1 Survey Data*

The same informal (i.e. non-validated) pre/post sustainability survey used to indicate student perceptions before and after the delivery of a sustainability learning module in the old first year course offered at UBC in 2014-2015 (Salvatore et al., 2015) was employed in the 2015-2016 academic year – once before students had experienced the first sustainability module (i.e. module 2) in APSC 100 and then again after the 2nd sustainability module (i.e. module 6) in APSC 101 was finished. In addition, a course exit survey was conducted to assess the students' perception of how well they achieved the learning goals of the two courses.

### *4.1 Course Learning Assessments*

Both mid-term and final exams were prepared based on the learning outcomes of each module, and in consultation with the whole teaching and curriculum development team.

## 5 Results and Discussions

### *5.1 Sustainability Survey Results*

2015-2016 response rates for the first and second deployment of the survey elicited response rates of 609/827 and 505/752, respectively. Comparing survey responses of students before they took module 2 (i.e. APSC 100) with the post-module 6 (i.e. APSC 101) survey responses allowed us to examine the shifts, if any, in the students' perception of their comprehension of sustainability concepts.

Figure 1 illustrates the change in the importance of the concepts 'systems thinking' and 'ecological resiliency' to the student's interpretation of sustainability. Notable differences are the 93.0% drop in "unsure" to the concept of systems thinking; and a 56.0% increase in those who consider it to be very important or critically important to the interpretation of sustainability.

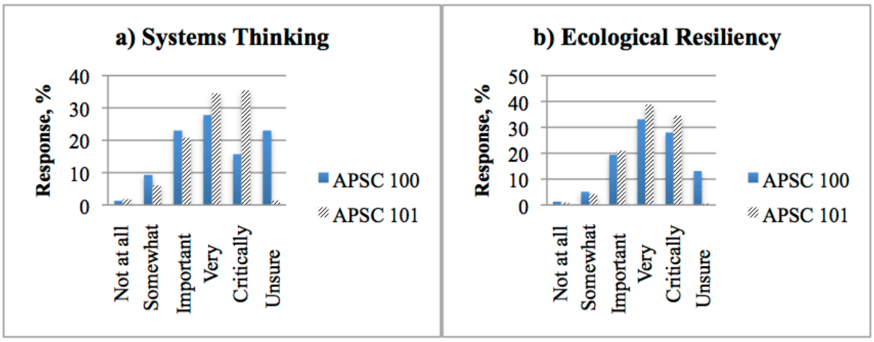


Figure 1: Shift in importance of: a) systems thinking; and b) ecological resiliency to the interpretation of sustainability. Significant at $p < 0.05$.

The changes in student interpretation of importance are summarized in Figure 2, including the data from the previous study (Salvatore et al., 2015). This figure illustrates the greater magnitude of change in APSC 100/101 student perceptions of each sustainability concept (i.e. 2015-2016 students taking the newly developed courses), compared to the changes in student perception suggested from APSC 150 survey data (i.e. collected from 2014-2015 students taking the old first year course). The figure suggests that perceptions of systems thinking changed dramatically in post-retrofit students (i.e. APSC 100 and 101 students). Decrease in the importance of "recycling" to sustainability for both versions of the first year program indicate the shift in students' thinking of sustainability being simply about recycling.

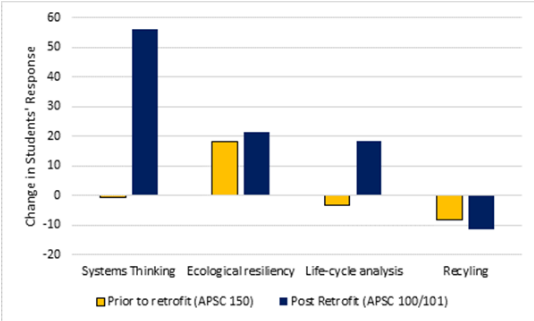


Figure 2: Change in students' response to importance of concepts in interpretation of sustainability (APSC 150 data from Salvatore et al. (2015).)

Figures 1 and 2 present some of the most interesting survey responses. Other data is also available.

### 5.2 *Exit Survey*

132 students (out of 752) participated in the exit survey. When rating the modules in terms of enjoyment, the top three modules were: module 1 – introduction to design; module 5 – engineering tools; and module 7 – defensible decision making. The least enjoyable modules were the professionalism and ethics (module 4); and sustainability (modules 2 and 6). Comments made by students indicate that they enjoyed modules with more concrete concepts and hands-on studio activities. Both modules 4 and 6 seemed to cover more nebulous concepts for first year students. Interestingly, Modules 6 and 7 were connected in that the latter was a concrete design problem (the design of a rainwater harvester collection system for a remote location), whereas the former focused on the context (global water scarcity), and first stages (identifying systems influenced by the design, design goals and criteria) of the module 7 design.

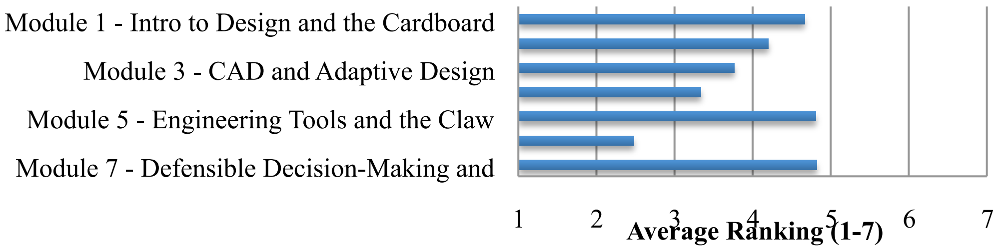


Figure 3: Student average ranking of contribution to development as an engineer by module (1 = smallest contribution, 7 = largest contribution)

Figure 3 indicates the ranking of students' perception on the contribution to their development as engineers. Module 2, where the three pillars of sustainability and systems were introduced, was considered to contribute to their development as engineers *after the whole course was done*.

Table 4: Student response on their agreement/disagreement with statements.

| "Having now completed APSC 100 and 101…" | SA | MA | N | MD | SD | U | Response |
|---|---|---|---|---|---|---|---|
| I have a much better sense of how engineers balance trade-offs and make decisions | 35.5% | 50.3% | 10.3% | 1.9% | 1.9% | 10.0% | 155 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| I have a much better sense of the role sustainability plays in decision-making by an engineer | 38.2% | 46.7% | 11.2% | 3.3% | 0.7% | 0.0% | 152 |

SA: strongly agree; MA: mildly agree; N: neutral; MD: mildly disagree; SD: strongly disagree; U: unknown

Table 4, which provides an indication of student reflection on their overall course experiences, suggests that students perceive a gain in sustainability learning, having taken APSC 100 and 101. Further data are available elsewhere (Ostafichuk et al. 2016).

### 5.3 *Final Exam Questions*

The final exam marks distribution for APSC 101 consisted of 42% multiple-choice questions; 38% short answers and 20% written answers. As summarized in Table 5, the assessment average for both 7 questions related to systems thinking, and 3 questions related to LCA concepts, scored close to the overall average mark for the final exam.

Table 5. Rate of correct answers in the final exam for APSC 101.

| Concepts | Range of correct answers | Assessment Average |
|---|---|---|
| Systems thinking (7 questions) | 52.7 – 97.7% | 77.3% |
| LCA (3 questions) | 70.0 – 93.0% | 79.5% |
| Overall final exam | | 77.9% |

### 5.4 *Next Steps*

Improvements to the current sustainability learning modules need to address two questions arising from this discussion.

1. How can the activities in APSC 100 and 101 increase student motivation (and enjoyment) to learn about sustainability?
2. What learning activities best support student development of metacognition and higher-order thinking, which, in turn, supports cognitive development?

#### 5.4.1 Improving Student Motivation

Dole and Sinatra (1998) suggest that motivation is stimulated by perceptions of:

1. a personal connection to the learning material
2. dissatisfaction with existing ideas
3. need for cognition (e.g. a required course)
4. social influences (i.e. it's easier to learn material if everyone else is also learning this material)

Further, if learning concepts are perceived as reasonable (i.e. plausible, coherent, and comprehensible), then students will put time and effort into thinking through material.

By developing activities that combine the above factors (for example, emphasizing sustainability concepts in daily student life and engineering life, while underlining the need to learn sustainability as a degree requirement, etc), student motivation will improve.

#### 5.4.2 Supporting Cognitive Development

Metacognition, critical thinking, self-regulated learning and other higher-order thinking skills support cognitive development as described by Thoma (1993). The more students test, explain, and critique their own understanding, and the understanding of others, the more they synthesize, integrate, and organize the knowledge they are trying to learn - and the more they develop their higher-order thinking skills (Dole and Sinatra, 1998).

Facilitated, structured, group discussions, graphic organization of knowledge, debates, and written summaries of open-ended discussions may afford opportunities for cognitive development within APSC 100 and 101.

## 6 Conclusions

Results reported in this paper indicate that students generally feel uncomfortable with the uncertainty and breadth associated with sustainability. It may be that improving student motivation and better supporting cognitive development will improve the student experience.


## Acknowledgements

The authors thank the UBC Sustainability Initiative and the UBC Teaching Learning Enhancement Fund for supporting this work. We also thank all the APSC 100/101 development and teaching team, and, in particular, Joerg Winter, who performed exceptional course development work.


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University of British Columbia Sustainability Initiative https://sustain.ubc.ca/courses-teaching/sustainability-learning-pathway/sustainability-attributes

# Water, A Natural Entrée into Sustainability Education

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## Abstract

Undergraduate students whether they are engineering students or other majors need easy access to the ideas of sustainability. Building a circular economy will take a gradual introduction yet first-year undergraduate students need a strong introduction to the underlying ideas and concepts of sustainability. Cyclic structures for carbon, nitrogen, sulphur, phosphorus and particularly industrial ecology are difficult and a bit too abstract for many students. Because students have first-hand knowledge of water, although typically not very deep, they seem to grasp the cyclical nature of water easier than some of the others. For this reason, the author has used a "Water for the World" course as a way to introduce undergraduate students, both engineering and non-engineering, to the ideas underlying sustainability, where sustainability as a concept encompasses macroeconomics, culture, the environment and technology.

The paper describes the "Water for the World" course that has been offered three times over the past five years during the Semester at Sea program. The course was listed as a global comparative lens course, which means that the course was changed for each voyage to reflect the countries visited. The total number of students taking the course numbered 120 with undergraduate engineering students representing about 25% of the total. During the academic year 2017 a further enhanced version of this course incorporating more economic materials will be taught at Colorado State University.

## 1 Background

In the spring of 2011, the author was approached to teach a course entitled "Water for the World" on the Semester at Sea program. This was indeed a challenge because the author is an educated aerospace and mechanical engineer, not a hydrologist. Much of the author's previous teaching had been in energy areas including renewables such as solar and wind as well as automatic controls and engineering design courses. The pre-existing "Water for the World" course syllabus included an introduction to the impact of water and sanitation (WASAN) on human health and productivity, the physical, chemical and biological unit processes of drinking water supply (DWS), wastewater and sewage treatment (WST), and the management of solid waste (MSW) with comparative discussions of the U.S., Mediterranean countries, Africa and the Caribbean using a book by Drinan (Drinan, 2001) as a textbook. The course was a typical three-credit hour course (45 contact hours) for undergraduate students of all majors (for example, environmental science, law, biology, and business and commerce) although a quarter of the class members were undergraduate engineering students, and years of study (but mostly first and second year university students). As the course progressed, the author realized that the students' backgrounds were insufficient for the course as defined. Classroom discussions drifted more and more toward issues of finite resources, sustainability and economic development particularly as the voyage itinerary moved from industrialized nations to developing nations.

The course was offered twice more on voyages in 2013 (westward circumnavigation of the Earth) and 2015 (a voyage through the Mediterranean, down the west coast of Africa, up the east coast of South American and through the Panama Canal ending in San Diego, California). Based on the results from the first time teaching the course, the course was modified to include more on water issues and less on treatment unit processes. This time the course used a book by Black and King (Black and King, 2009) and a revised version of Drinan (Drinan & Spellman, 2012) as the course textbooks. The course began with a full explanation of the hydrogeological cycle. The ideal cycle was illustrated without any human intervention first and then man's activities were superimposed on the cycle. Topics covered included: water for drinking, hygiene and sanitation; irrigation, agriculture and food; industry and energy; ocean and fisheries; transport; rapid urbanization; altered flows; drained wetlands; droughts and floods; pollution; disease and the impact climate change will likely impose. Each of these topics was accompanied with sufficient water, demographic, economic and energy data to provide the student with information relating to cultural, economic, environmental and technical sustainability along with the implications for future sustainable development. The need and role of a water ethic (Barnett, 2012) was also introduced. In addition, this course let the author (Siller *et al*, 2015) try to dispel the myth of "engineering as problem solving" and instead reinforce that water issues, in particular, are not problems to be solved but rather challenges to be managed.

Besides mandatory attendance, in-class discussions, a field-lab report and two examinations, a major research paper of 3000-5000 words was required of each student. Some example paper topics included: the cultural conflict between a river as god and therefore pure (the Ganges) vs. the reality of one of the most heavily polluted rivers in the world; the development of water infrastructure and a water ethic in Singapore; women's rural water struggles; water allocation methods and water rights in Japan; the effects of water scarcity in a changing world and some (possible) sustainable options; the great garbage patch in the Pacific Ocean; water and the developing colonias of Texas; village water purification standards worldwide; problems with hydraulic fracturing; meat consumption and water use; the role of desalination in Israel; the Balkan flood of 2014 that no one heard of; a need for change in water resource management; the benefits and risks of genetically modified salmon; new water usage models for agriculture; water's role in the economic development of Thailand: investigating a nation with the conflicting interests of industrialization and hydro-environmental sustainability; the impact of global warming above the arctic circle; water in the song kran and loy kratong festivals; the tragedy of the commons: our world's fisheries; agricultural water management in monsoon India; biological remediation of heavy metals, eliminating water borne diseases through improved hygiene; is desalination the answer to California's water crisis?; and water, women and microfinance for sustainable development. The students were also required to do an in-class presentation of their papers. From the papers and presentations it was obvious that the students had acquired a deeper understanding of most of the world's water issues and challenges and that sustainable development will require significant changes in the management of the Earth's water resources in the future. However, the course was not run as an experiment so there were no formal studies made of student acquired skills or insights through follow-on interviews and evaluations. This could certainly be done in the future and should be considered the next time the course is offered.

The major shortcoming of the course was not including a closer coupling of additional macroeconomic ideas and models that the students can query to enhance their understanding of the linkages between the economy, the environment and society and to fully understand the need for a change of thinking with regards to economic growth as one of the primary drivers of local and global decision making. Hopefully, this shortcoming will be eliminated in the latest version of the course scheduled for 2017 and described in the following section.

## 2 Current Course Description

The three major goals for this new introductory course are

1. Use an easily understood analogy for sustainable development and the circular economy, in this case, the hydrogeological cycle and the urban hydrological cycle;
2. introduce the concept of a low or zero growth economic model; and
3. dispel the idea that most problems are solved and replace it with the idea that problems are managed in their current context.

These are unusual goals for an introductory engineering course but they seem necessary as issues for our students to grapple with at this early stage in their careers. The major outcomes for the students would be to be able to define the key aspects of sustainability relative to water issues, society at large, and its dependence on natural resources with some understanding of the ethical obligations of the professional engineer.

The course begins, as in the previous course, with the photograph known as the "blue marble." The Apollo 17 crew on their outward trip to the Moon took this iconic photograph on December 7, 1972 from a distance of about 45,000 kilometers. The photo became an important part of the environmental movement of the early 1970s and was viewed as a symbol of Earth's frailty, vulnerability and isolation, that is, the Earth as an island separated from any other islands by nearly unimaginable distances. The Earth's blue color is the result of nearly 70% of the Earth's surface being covered with water. One might think that the Earth is mostly water. However, with an average depth of about 3.7 kilometers, whereas the Earth's radius is 6,371 kilometers, the Earth's oceans represent only a thin film of water and not an unlimited resource. This simple photo sets the scene for discussions on cultural, economic, environmental and technical sustainability.

To set the stage for sustainability discussions and to introduce the students to the idea of reading original sources, the author provides the students with a comprehensive reading list. The first is a section from <u>Collapse</u> (Diamond, 2005) and presents Diamond's list of factors leading past societies to collapse. He lists five factors: environmental damage, climate change, hostile neighbors, trade partners, and societal response to these factors. Of course, Diamond's list of societies that have collapsed are all of the micro variety (e.g., small island cultures) rather than the collapse of the entire Earth's society. But the factors provide a framework for further discussions as the course progresses.

A quick run-through of water availability convinces the students that water resources are not unlimited. Of the water on Earth, 97% exists in the saline state, that is, ocean water with a high salt content. Of the remaining 3% only 0.3% is available annually as freshwater for all the Earth's inhabitants and plant life and this is definitely not uniformly distributed in space or time. Most of the freshwater is locked in icecaps, glaciers and groundwater; the later is another form of a fossil resource available with energy for pumping. The hydrogeological cycle presents the cyclic nature of water and its endless operation. The description is usually begun with evaporation from the oceans from solar heating; convection of water molecules into the atmosphere (a greenhouse gas); precipitation over the oceans and land masses; evapotranspiration from land, land-based water bodies and plants; surface runoff and groundwater accumulations with the water eventually returning to the oceans. The water balance is shown with discussions about the conservation of water. Water, like many resources, is conserved and in general is neither created nor destroyed. This is also true for most mineral resources; this is contrasted with the combustion of fossil fuels whose chemical composition is altered during use leading to the formation of additional greenhouse gases and other toxic compounds.

The major water topics from the previous course and now introduced along with a description of the water molecule in order for the students to grasp the significance of water's amazing properties such as volumetric expansion when changing from the liquid to the solid state, droplet formation, etc. A major activity within this portion of the course is the discussion of a water ethic (Barnett, 2012). Students will form active groups to develop and defend their group's water ethic.

Water requires energy either for production (desalination), transportation (pumping) or treatment and thus is similar to the manufacturing of goods from reusable, reprocessed and recycled materials. At this point, introducing the urban hydrological cycle illustrates the important elements in a circular economy as shown in Figure 1. Here raw water enters the Drinking Water Supply ($DWS_1$) facility in City 1. Energy is applied as input for treatment. The drinking water is distributed throughout the city and waste and sewage is collected and input into the Wastewater and Sewage Treatment ($WST_1$) facility. Again energy is applied for the treatment processes and the water is discharged into the receiving waters where it proceeds to the next city and the process is repeated. Solid Waste ($SW_1$) from the city is furthered processed into useful products by other industries and businesses. By the very nature of the hydrogeological cycle the entire system repeats as a cycle with no beginning or end. Water, a natural resource, is continuously recycled with energy as the primary process input. This then can be the basis for further consideration of a circular economic model but first it is necessary to introduce ideas about growth vs. development and macroeconomic modeling.

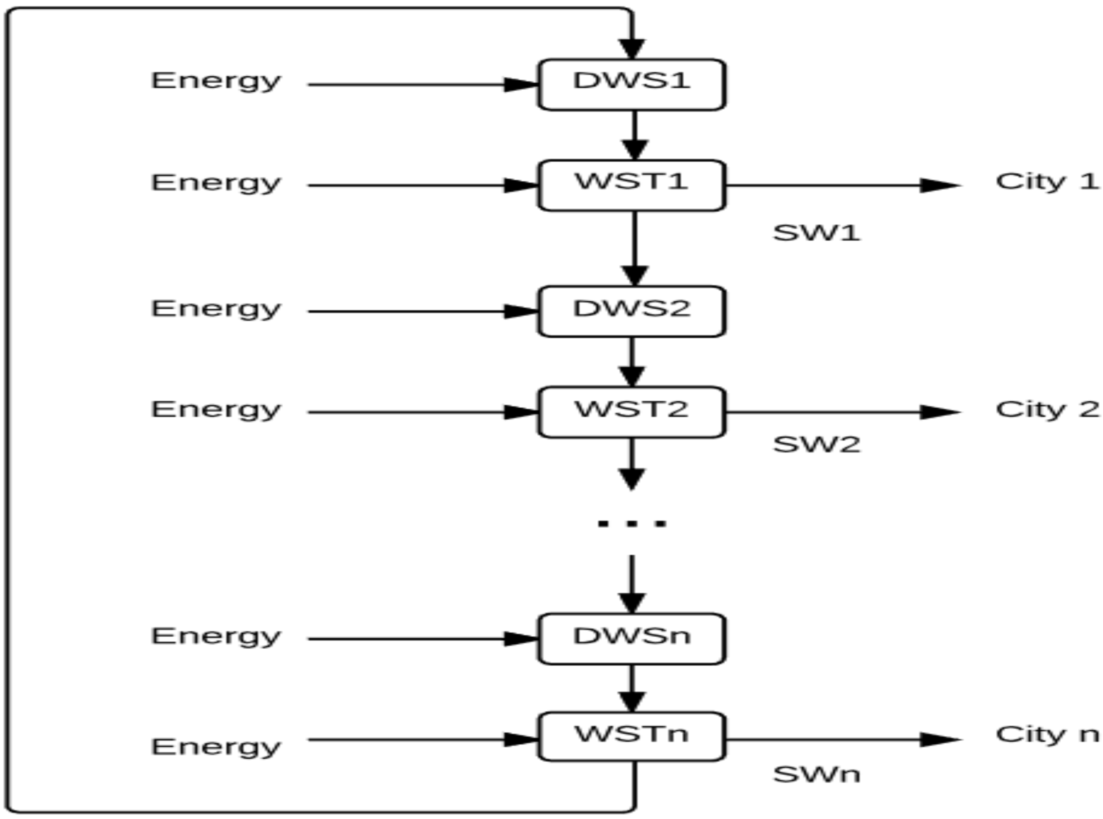


Figure 1: the Urban Hydrological Cycle

Growth is usually thought of as a process involving predominantly quantitative changes, e.g., increasing an economy's size by a given percentage, whereas development more often involves qualitative changes such as improving society or reducing environmental impact. What is not needed is growth, what is needed is development. By these definitions, development more easily pairs with sustainable than growth does, thus, sustainable development is the key phrase.

As an example, consider the implications from a global economic growth rate of 5% on the global economy. This means that the current world economy of US$60 trillion would have to expand to US$240 trillion (in current dollars and assuming no inflation) in the year 2044. It is hard to imagine that resource extraction and use levels could come anywhere near this. For example, pumping 90 million barrels of oil each day and selling each barrel for US$100 only amounts to US$3 trillion, or 5% of the current global economy. Even a more modest economic growth rate (proposed by many economists and policy makers) of 3.5% would result in the same economic level in the year 2056. Another way of saying this is that for a global population of eight billion, the global per capita GDP would have to be US$30,000. Note that both 2044 and 2056 are within the working lives of our current students. As witnessed today, economic growth is already slowing to near zero levels of growth particularly in the industrialized nations, e.g., Japan's 30-year stagnation. And, of course, any growth rate will lead to some inflation.

Not only is perpetual economic growth not sustainable it also is not attainable. Continued emphasis on economic growth leads to boom/bust cycles, does not provide full employment, and exacerbates income inequality. Most models that our students see have beginnings and endings. Many mathematical economic models (Dasgupta, 2008) begin with the assumption of unbounded upwards growth but they allow for dips; however, following the dip the trajectory always continues its upward rise. Students need to see models that are circular or cyclical as an alternative to exponential progressions. The hydrologic cycle can play this role for students. It is easy to understand yet introduces concepts that are essential for understanding sustainable development and the circular economy. Cyclic systems also may be used to discuss the idea of a dynamic system as opposed to a stagnant system. Again, water is not uniformly distributed either in time of space with resulting dynamic system characteristics.

Continuing with the theme of reading original sources, the students are assigned (Malthus, 1798). Malthus's major mistake at the end of the eighteenth century was that the Earth already was the island and not just England. Some short readings from Adam Smith (Smith, 1796) develop the formal introduction to capitalism including Smith's identification of its shortcomings. Both of these books (Malthus, 1798) and (Smith, 1796) are available free of charge from Amazon. A jump is made to contemporary times (Meadows *et al*. 1972) and its more recent updating (Meadows *et al*, 2004). Here the models are based on systems dynamics (Forrester, 1971). The author provides the students with a Microsoft® Excel® World Model that they can exercise to determine sensitivity to various input tables and model assumptions. To counter arguments that <u>Limits</u> <u>to</u> <u>Growth</u> (Meadows *et al*, 1972) did not include pricing structures and technological innovations, the students are presented with more traditional statistical economic models (Victor, 2008) and (Victor & Jackson, 2015) for low growth or zero growth economies. These models may also be downloaded from Victor's website (Victor, 2008b).

The time apportioning for the course breaks down as follows: about 50% of the class time is devoted to water, its major issues, challenges and limitations; about 15% is used for the discussion on the unit operations of water treatment, wastewater treatment and solid waste processing and the urban hydrological cycle including its relationship to the circular economy; about 20% is used in the discussion of macroeconomics including the exercise of the World Model and the Zero Growth model; and the remaining 15% is used for in-class project presentations and examinations for course assessment.

Like water and energy (Hagens, 2015), economies will also require managing to prevent collapse (Das, 2016) and (Victor, 2008a). Industries will have to develop design methods including sustainable practices (Barth, 2016) for cradle-to-cradle product development strategies. Global supply chains of reusable, recyclable and reprocessable materials will have to be inventoried and managed. Throughout the course, management of challenges is emphasized over problem solving. Problem solving is an ontology that is embraced by many engineering faculty and most engineering students. This ontology has led to an over emphasis on problem solving courses as the major component of the undergraduate engineering curriculum. In order to produce students that are capable of living and working in a sustainable future, such over reliance on problem solving needs to be restricted and replaced with a more helpful transdisciplinary management approach. All of the challenges of this course are presented as issues to be managed with the added caveat that there are few if any solutions and those solutions that do exist, normally exist only on a local scale. True sustainability exists in a global context and therefore requires management approaches.

## 3 Summary

The paper presents the historical development of the course entitled "Water for the World." The course has been taught three times over five years. The course originated primarily as a course in water and sanitation concentrating on the unit operations of the treatment processes for clean water and wastewater and sewage and has evolved into a course on the issues, challenges and limitations of one of Earth's most precious resources—water, including an introduction to the circular economy and economic models not based on exaggerated and unrealistic economic growth rates.

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# Learning for sustainable water and sanitation services

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**Abstract**

Water and sanitation services, and the utilities providing these services, are one of the cornerstones of functioning societies. Safe drinking water is essential to human health and well-being. Sanitation plays a central role not only in securing human health but also in enabling conglomerations of human settlement thrive without compromising the state of environment. In this paper, sustainable development is examined from the point of view of water and sanitation services. The paper discusses a PhD project and combines insights from several empirical studies and literature. It is argued that sustainable development is a dialogue of values and learning process. It is not a separate add-on of greening activities or tweaking energy and chemical consumption of the water and sanitation services. Instead, it is a chance to reflect on the ways of thinking about the service itself. It is argued that this learning process necessitates water and sanitation engineering community to be more reflexive and open.

## 1 Introduction

This paper is not a typical conference paper – it does not present findings of a particular research, practical case study or a systematic literature review. Instead, it is a reflection upon a PhD project. I will refer to the research projects I've been involved with, but will not discuss specific details of them. I aim to present a very concise synthesis of what I've learnt during the process. In a sense, this paper is a narrative of my learning process that started in 2009 as I embarked on a journey eager to define the learning outcomes necessary to make water and sanitation services more sustainable. In the process, I understood that I first need to learn what sustainable development is, what water and sanitation services are, and came to the conclusions that it all boils down to learning. Furthermore, I've come to understand that defining detailed learning outcomes can be too restrictive and contrary to the core idea of sustainable development (see also Sterling 2001, 74).

## 2 What is *sustainable development*?

Considering the EESD audience, it is probably unnecessary to dwell on the concept of sustainable development. However, because sustainable development is not something that can be exactly defined, but is more a dialogue of values (Ratner 2004), it is always recommendable to open one's understanding behind the concept. One useful way to understand sustainable development is to look at how it composed and analyse its historical development. These simplified narratives, or meta-theories, can serve as a heuristic framework to describe the discourse of human development and its relation to environment.

## 2.1 Sustainability

The concept *sustainable* or *sustainability,* has its roots in the 18th and 19th century forestry and fishery. It was used in the context of *sustainable yield*, i.e. learning to live off the interest of the available natural capital, not of the capital itself, and that the resource is not exhausted and its use can be continued or sustained indefinitely (see Grober 2012 for extensively detailed account of the concept's cultural history).

In the 1960s and 1970s, all over the industrialised world, environmental concerns gained ground, and we can talk about the birth of *environmentalism*. It was a more holistic approach than the earlier management attempts of local environmental problems and setting up of conservation areas to save pristine nature. The concern for environment was further heightened in the 1980s as global environmental problems, such as ozone depletion and climate change, became known to wider audiences. These problems were no longer perceived as separate issues that could be managed by the development of technology or social organizations. Instead, there was seen to be a total crisis between humanity and nature, and it was feared that the basic conditions for human existence were being jeopardized. (see e.g. Macnaghten & Urry 1998, Hajer 1995)

## 2.2 Development

The surge of *environmentalism* coincided with the growing criticism of post-war growth theories, and all in all, the idea of *development*. The prevalence of ideas based on economic growth, modernity and industrialization were challenged based on the environmental problems, but also social problems such as hunger, poverty and wars. It was no more self-evident that economic growth could last indefinitely and would benefit all. Furthermore, even the desirability of everlasting economic growth was questioned. (see e.g. Norgaard 1994, Rist 2014.)

## 2.3 Sustainability + development = sustainable development

In 1983, the General Assembly of the United Nations set the World Commission on Environment and Development (so called "Brundtland Commission") to create a global agenda for change and to propose long-term environmental strategies for achieving sustainable development by the year 2000 and beyond (WCED 1987). This is the first time that aspirations related to environment and development were combined in a high-level international politics. In 1987 the Commission published its report *Our Common Future*, that made the term "sustainable development" widely known. (see Blewitt 2008).

## 2.4 Sustainable development as a learning process

As stated, sustainable development aims to address simultaneously the various concerns related both to social and environmental issues. These are systemic; they cannot be solved independently of a large number of complicating factors (Norgaard 1994). According to systemic understanding of sustainable development, environment (natural systems) and human systems (society, economy, culture) form a nesting system (see Sterling 2001, Ainger & Fenner 2014). Environment forms the basis of all life and, thus, it provides the context and boundaries in which everything else is set (see Steffen et al. 2015 for contemporary presentation of limits). Within the natural system, humans have created society, which operates according to cultural norms, legislation and institutional regulations. Society, then again has created economic systems to serve its purposes.

Both natural and human systems are complex. Furthermore, they are both dynamic systems. Thus, also the concept of sustainable development is complex and dynamic (see also Newman 2005; Blewitt

2008). Sustainable development is about what we value and what we consider worth striving for. Values change as the world changes, i.e. as our skills, knowledge and capabilities change. Thus, as Blewitt (2008) points out sustainable development both requires a dialogue and is a dialogue of values. It is not a goal, but rather an on-going process, that requires continuous re-evaluation, learning and re-learning (Voß, Truffer, & Konrad 2006).

It is widely recognized that in the face of sustainable development challenges, the mechanistic and reductionist ways of thinking are not adequate, but systemic, holistic, contextual, subjective and pluralist premises are needed (Norgaard 1994; Sterling 2001). This is profound change, or even paradigm shift (Gough & Scott 2007) that is called for. It necessitates collective learning throughout the society (Norgaard 2004). Furthermore, according to Gough and Scott (2007), sustainable development should be viewed as a fresh and challenging framework for thinking about everything we are and what we do. In this line of thinking, the ambiguity of the concept should be embraced as it can act as a powerful tool of thinking, and help understand the uncertain and complex world we live in. As Blewitt (2008) argues, sustainable development may productively function as a learning process.

## 3 Sustainable development in the context of water and sanitation services

Now, that the concept of sustainable development has been discussed in general, let us take a look at what it could mean in the context of water and sanitation services. These services are important for hygiene and health of both people and environment, and furthermore they are connected to various economic activities. As Bakker (2003, 51) writes "Clean water was recognized to be critical element for continued industrial production and a functioning labour force." Thus, it can be said that water and sanitation services enable the functioning and development of modern societies – thus making them essential services (McNabb 2005, Castro 2009). What about the relation of these services to sustainable development?

### *3.1 Focus on environmental aspects and the long lifetime*

I interviewed Finnish water supply and sanitation professionals to learn how they understand sustainable development (Takala 2013). I thought this approach makes sense, as, after all, sustainable development is socially constructed and reconstructed (Hajer & Versteeg 2005). The Finnish water sector experts perceive sustainable development mainly from the environmental point of view, and especially regarding the use of energy and chemicals. In addition, they highlight the choice of materials and especially durability of networks. The former can be said to represent the classical view of environmental protection and environmental engineering (Barraqué 2003), but it is debatable if it suffices as sustainable development. This view is historically understandable as especially sanitation was developed to tackle water pollution problems, and there is tradition of having a strong emphasis on environmental engineering. It is problematic, however, if sustainable development is considered to be inherent to water and sanitation services as this suppresses the idea of continuous development and learning.

The latter view, emphasis on the durability and the longer life span, highlights more the tradition of civil engineering. Again, this is a fully legit concern, and can be explained by the development history of water sector professionals (Barraqué 2003). However, it is questionable whether it alone suffices as sustainable development. Furthermore, there is a danger that excessive emphasis on the long lifetimes and huge investment costs of the infrastructure makes water and sanitation services rigid, providing little freedom to opt for changes (see also Krantz 2012; Voß, Truffer, & Konrad 2006). This is problematic if we accept that sustainable development is about adapting flexibly to uncertain and ever-changing environmental and social systems. Malmqvist et al. (2006), as a matter of fact, argue that water sector is characterised by conservatism; development is understood as the connection of newly built or peri-urban areas to existing networks, or minor improvements to water treatment processes.

### *3.2 Contradictory understandings of sustainable development*

Both views, the one focused on environmental aspects and the other on long lifetimes, were seen to contradict economics of water and sanitation services. Basically, it was seen that sustainable development contradicts economic rationality. Another example of this contradiction is consumers' aspiration to conserve water which contradicts the water utilities' urge to sell more water. This contradiction was more highlighted in another study, in which me and my colleague interviewed Finnish water utility managers and customers (Heino & Takala 2015a,b). Customers seem to have a strong moral sentiment that wasting water is wrong, and that the water utility should encourage reasonable water consumption (Krantz & Drangert 2006 have made similar observations in Sweden). This conservation sentiment, then again, did not cohere with the managers' ideas on water and sanitation services (see also Strang 2004).

Perhaps, most worrying is that the interviewed experts and managers perceive sustainable development to contradict the purpose, or the ethos, of water and sanitation services. This is the case, if the management of water and sanitation services is technocratic and managerialist, and sustainable development is perceived as a separate add-on. Then again, at the same time sustainable development is seen to be inherent to water and sanitation services. These kinds of contradictions and tensions can act as a catalyst to discussion and reflection process. However, it is debatable whether this kind of discussion takes place. Many of the interviewed experts and managers, quite the contrary, regretted that normally, there is hardly any time to ponder on these more "philosophical" questions. Furthermore, at least in Finland, there is hardly any public discussion on the sustainability of water and sanitation services. For example, the analysis of the annual reports showed that sustainable development is not really discussed, and that the focus is on managerial discourses such as efficiency, result and profit orientation (Heino & Takala 2013).

### *3.3 Narratives on the development of water and sanitation services*

It seems that one key question is how we understand water and sanitation services. Similarly, as with the concept of sustainable development, I find it useful to look at the development of these services. For example, Graham and Marvin (2001) discuss the development of networked infrastructures and conceptualize this development in terms of *modern infrastructural ideal*. According to them, the ideal was that public services should be available to all. Bakker (2003) describes a similar process in the UK, where, before 1970s, water was considered to be a service supplied at subsidized rates to citizens to advance social equity.

The universalization of water and sanitation services was achieved by hierarchical government and large-scale centralised technologies (Swyngedouw 2004; Castro 2009; Karvonen 2011). According to Graham & Marvin (2001), the ideal was built on the professional culture of engineering that rested on rationality and mechanics. Sofoulis (2005), analyses development in water and sanitation sector conceptualizing it as *Big water*: centralized public or corporatized utilities pursue large scale engineering projects and assume virtually all responsibility for the water and sanitation services.

From the 1960s onwards, there has been powerful critique of the assumptions underlying the *modern urban infrastructural ideal*. It has been criticised as totalising and reductionist process that treat humans as mere objects (Graham & Marvin 2011; Strang 2004). According to, Graham and Marvin (2001) criticism has later heightened due to changes caused by privatization, liberalization, and globalization. In addition, lack of maintenance and rehabilitation have caused reason to doubt the power of the ideal. Graham and Marvin (2001), conceptualize the idea of *splintering urbanism* as a response to the challenges. According to them, especially the telecommunications and broadcasting sectors have changed already significantly. There are also changes occurring in the energy and transportation sectors. However, it seems that for several reasons, change in the water and sanitation sector is slower, and the *big water,* and the supply-side management associated with it, is still dominant (Sofoulis 2005; Bakker 2003).

In Sweden, Krantz and Drangert (2006) analyze the changing role of households. Until the 1970s households were considered as anonymous subscribers with no responsibility related to water and sanitation services. After 1970s, and the introduction of wastewater tariff, households became to be viewed as customer. In an effort to make households accept higher prices, they needed to be informed about the water and sanitation systems and their costs. Only quite recently have water utilities seen the need to involve households or residents. This change has occurred in relation to the source-control measures of hazardous substances from households (Ibid; van Vliet & Stein 2004), and water conservation measures (Chappells & Medd 2008).

### *3.4 The compatibility of water and sanitation services with sustainable development*

So, how well do the narratives of sustainable development coincide with that of the understanding of water and sanitation services? The studies already discussed, indicate that in Finland the current understanding is production-oriented, relying on technocratic and managerial thinking (see especially Heino & Takala 2015a). Castro (2009) seems to agree, arguing that the management of water and sanitation services is dominated by techno-centric approaches. Bakker (2003), furthermore, conceptualizes the current management paradigm of water and sanitation services as *market environmentalism*, which is characterized by emphasis on efficiency, economic equity over social equity, planning for scarcity, demand-led solutions, and regulatory decision-making.

It can be argued, that the same developmental forces (problems related to environment and development) that gave birth to the concept and idea of sustainable development, also form the basis of change from hegemony of state-led, hierarchical, centralized water and sanitation services, to a more splintered, participatory and open idea of the services. However, at least in Finland, this change is still very much in progress. From the point of view of water and sanitation services, only people who have a contract with the utility, are considered and their role is limited to paying the bill. It seems that *consumers* still just reproduce already embedded arrangements instead of being active participants (Chappells & Medd 2008).

Sterling (2004) presents a taxonomy of sustainability transition to educational institutions, which we can adapt to water and sustainability services. At the lowest level, there is no change and response is denial, rejection or underestimation. On the second level transition is weak, sustainable development is mainly seen as a separate add-on to existing operations, structures and such. This second level can be characterized as thinking about sustainable development in water and sanitation services (cf. education about sustainable development) and changes are mainly cosmetic. On the third level, transition is strong as sustainable development is considered to be a built-in issue involving true 'greening' activities. This can be characterized as water and sanitation services for sustainable development (cf. education for sustainable development). At the highest level, transition is very strong, including a rebuild or redesign of structures, when we can talk about sustainable water and sanitation services.

I argue, that in Finland, the transition to sustainability is weak as sustainable development is mainly perceived as an add-on. Based on literature, I would argue that internationally the transition is somewhere between weak and strong, as sustainable development is mainly seen as add-on, but there are some 'greening' activities going on. In addition, I think that many of the calls to return to the basic ethos of water services resonate with idea of very strong transition and sustainable water and sanitation services (e.g. Barraque 2009; Chappells & Medd 2008; van Vliet, Chappells & Shove 2005; Castro 2009; Heino & Takala 2015a; Swyngedouw 2004; Karvonen 2011; Krantz 2012). In the last section of this paper, I will shortly discuss transition to sustainable water and sanitation services would imply.

## 4 Reflection: Sustainable water and sanitation services

If we take as a starting point that sustainable development is complex, contested and dynamic, and basically it is a dialogue of values, then it means that simple add-ons of, for example, decreasing the use of energy and chemicals, are not enough.

If we aspire for sustainable water and sanitation services, it is not enough to have an operational focus on 'getting the job done' without consideration of how the job was defined or whose interest are served (cf. Gough & Scott 2007). Instead, if we want a dialogue and a learning process on sustainable water and sanitation services to take place we need a dialogue on the ethics and ethos of serving the public good (Castro 2009; Barraque 2003; McNabb 2005). As a matter of fact, water and sanitation sector has adopted customer-orientation and participatory processes. However, as Castro (2009) argues these tend to be reduced to technical and administrative dimensions.

Dialogue would necessitate co-management (van Vliet, Chappells & Shove 2005) or co-creation of value (Heino & Takala 2015a) between the providers and beneficiaries of water and sanitation services, and better understanding of the everyday water culture. This implies shifting attention from water supplies to the uses that people make of water, highlighting the social side of water's hydro-social nature (Linton 2010). Fostering dialogue means that the epistemic community of water and sanitation engineers needs to embrace the idea of open and shared expertise. This means that they have to deal with uncertainty and complexity. As Barraqué (2009) argues, this can make water engineers feel awkward and insecure. But also citizens need to assume more responsibility and participate in the definition and provision of water and sanitation services (Ibid).

We need further research on how mental models or thought patterns of the epistemic community of water and sanitation engineers develops. As, Mulder (2015) pointed out in his key note in EESD15, it seems that despite all the activities and declarations to include sustainable development into engineering education, the students are drawn into a technocratic identity which is counterintuitive with sustainable development.

## Acknowledgements

I am grateful for *The Finnish Concordia Fund's* travel grant that enables my participation in the EESD2016 conference. Furthermore, the financial support of *The Alfred Kordelin General Progress and Education Fund* and *Erkki Paasikivi Foundation* for the PhD project are gratefully acknowledged. I would also like to acknowledge the reviewers for their valuable comments and Prof. ir. Bernard Mazijn for his understanding and advice, and the whole EESD community for inspiration throughout the years.

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# Design for Interdisciplinarity: the Home for Environmentally Responsible Engineering (HERE)

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## Abstract

Interdisciplinarity remains a fundamental challenge in education for sustainable development (ESD) partly because it remains a challenge in engineering education and higher education as a whole. Disciplines help frame problems and so predict solutions, so economists, architects, and social workers see the same wetlands or neighborhood through three different lenses. Translating across disciplines is thus more than a matter of vocabulary or teaching loads; true interdisciplinarity requires constant conversation, iteration, and open process. And because, as many have noted, true ESD must be grounded in ecology, thermodynamics, and other natural sciences, as well as economics, politics, psychology, and more, engineering coursework in sustainability has to help students think through problems in more than one way.

In HERE (a Home for Environmentally Responsible Engineering), our first-year living-learning community for students interested in sustainability, we integrate multiple disciplines through a yearlong sequence of three courses. Our approach is to see sustainability as an integral part of **design**, a set of tools for helping to set problems as well as to solve them. With the help of design faculty in multiple disciplines as well as faculty versed in communication, we begin by introducing students to a generalized design process: recognizing and defining gaps between present and desired outcomes, then planning and exploring solutions, then experimenting with design validation and review. All three courses, spread out over Fall, Winter, and Spring quarters, follow this process, which we believe undergirds most disciplines.

The three courses are arranged in narrowing circles, from global sustainability in the fall to regional sustainability in the winter, to greening-of-the-campus initiatives in the spring. With each iteration, design projects lengthen, and more attention is paid to the process itself. Faculty from various disciplines help design the curriculum, and guest lecture. Thus, by Spring, when our freshmen propose solutions to environmental and social problems on campus, they see these problems in the light of regional as well as global sustainability. In each of the courses, we cover five content areas: energy, water, carbon, biodiversity, and food. So, for example, we move from global lessons on the hydrologic cycle and water scarcity in the Fall to regional issues of water quality and treatment in Winter, to campus consumption, fixtures, and policies in Spring. Fall projects look at hydropower on the lower Mekong River, Winter projects try to mitigate agricultural runoff in the Wabash River, and Spring projects propose campus-wide plastic water bottle policy.

# 1 Introduction

## *1.1 Interdisciplinarity*

Everyone acknowledges that interdisciplinarity is an integral part of engineering education for sustainable development (EESD). Recognizing and transcending disciplinary boundaries is crucial for meaningful sustainability education, for engineering education, and for higher education in general. In the last several decades, interdisciplinary education has been called for repeatedly, in the context of higher education most notably in the United States by the Boyer Commission (1998), the National Research Council (2003), the National Academy of Sciences (2004), and the National Academy of Engineering (2004). In the engineering context, "data show that with regard to the study program, the competence for interdisciplinary cooperation appears to be central" (Barth *et al.*, 2007; see also Thomas, 2004 and Borrego and Newswander, 2008). And in education for sustainability (or ESD, education for sustainable development), international initiatives from the Tbilisi Declaration to the Declaration of Barcelona insist that ESD "should… give a depth in the disciplinary knowledge while also providing opportunities for interdisciplinary thinking and action" (Svanström *et al.*, 2008). While disciplines can define, produce, and maintain relatively stable bodies of knowledge and professional competencies, many educators would agree that "deep learning can be inhibited if the interests or backgrounds of students have a strong disciplinary focus" (Warburton, 2003; see also Blewitt, 2004). Project Kaleidoscope (2006), which advocates for strong undergraduate STEM (Science, Technology, Engineering and Mathematics) programs, lists several "barriers and challenges to changing the system" including "organizational barriers that create competitive instead of cooperative environments among departments and organizations; cultural differences between disciplines and agencies; lack of innovative approaches in education; scientific disciplines [which] are too compartmentalized and tend to focus research on disciplinary interests." Case studies from various institutions have shown that faculty can be "ideologically resistant to curriculum changes that emanate from outside the bounds of their discipline" (Alabaster and Blair, 1996). "Significant institutional and intellectual barriers for the emergence of integrated systems thinking… remain major problems in both research and education" (Ashford, 2004).

## *1.2 The Challenge*

But interdisciplinary engineering education for sustainable development can be tricky to do *well*. There is an intrinsic degree of difficulty to interdisciplinarity. Disciplines have determinate subjects, methods and modes of investigation, histories and historiographies, as well as academic departments and hiring practices. Philosophers, sociologists, mechanical engineers and physicists all constitute discrete discourse communities, each with distinct "conventions, a vital history, mechanisms for wielding power, institutional hierarchies, vested interests, and so on" (Porter 1992). To attempt to cross these disciplinary lines is to risk appearing dilettantish, uninformed, to speak words without speaking a language. And yet, to attempt to abandon disciplinary lines altogether is to risk losing valuable tools, techniques, and terminology. Thus, cross-disciplinary and multidisciplinary collaborations, in practice, are often mixtures rather than compounds, with teams that comprise representatives of various disciplines, each speaking past one another (Newell 2001, Newell 2013). True interdisciplinarity, by contrast, means knowing two languages, as it were, and being conscious of when and how to shift from one set of methods to another. Interdisciplinary skill means being able to be disciplinary and not disciplinary at the same time. The field of religion and ecology, for example, and the field of literature and science, all too often devolve into conquest and colonization, scholars of religion more interested in "the metaphysics of ecology" than in the mechanisms of predator-prey relationships, literary critics fluent in the symbolism of the laboratory but ignorant about science itself (see Bauman et al., 2011 and Latour, 1999).

More pragmatically, interdisciplinarity constitutes a challenge in higher education for institutional reasons. Institutional structures tend to follow disciplinary lines, which makes it hard even for those who are willing and able to think and work on interdisciplinary teaching projects to handle the full-time equivalencies (FTE) problem. That is, if a professor in a history department wants to teach a course on the history of water privatization with a professor of civil engineering, more often than not, the course cannot count towards both professors' teaching requirements. And even when the bookkeeping requirements are satisfied, the ethos of academia tends to reward disciplinary specialization rather than translation across disciplines, and favors individual publications over co-authored collaborations.

For students—those in engineering fields, in particular—an added problem is professionalization. Engineering fields are not disciplines precisely, but professions, organized not just around the production of knowledge but around professional identities and the exigencies of employment. It would seem that this difference might actually make interdisciplinarity easier, given that professions tend to employ more wide-ranging methods in solving more varied problems than disciplines do. And yet, in practice, the effect more often is to turn "that's not how I think" into "that's not my job." Students who major in electrical engineering differ from students who major in chemical engineering less because they solve different problems differently, than because they want different careers (Minster *et al.,* 2012).

Even more importantly, perhaps, students frequently sort into STEM fields because they show skill in math and science classes at the secondary level. These courses are generally taught with textbooks that break material into discrete units, emphasizing content at the expense of context (Hyman, 2002). Interdisciplinary learning, by contrast, requires contextual awareness. Moreover, as the Perry model and Bloom's taxonomy suggests, college students tend to see knowledge as relatively static, so recognizing multiplicity, seeing problems modally, and working synthetically is challenging at first (Perry, 1981). It is hard enough to learn one discipline, let alone two, let alone to know how to navigate between the two meaningfully and fairly.

And if all of that is hard, it is that much harder when the content addresses sustainability, resiliency, and sustainable development which is so thoroughly interdisciplinary. Problems like inadequate public water systems are wildly complex and overdetermined. They deserve the term "wicked problems" (Hess *et al.,* 2014). Various disciplines construct the problem in different ways, and so seek different solutions: political theorists and sociologists might look to management and decision-making norms or frameworks as causal factors, whereas economists and civil engineers might point out hidden social costs and failing infrastructure. Whose terms and methods best help students understand the challenges of urban redevelopment or the perils of industrial agriculture? Ecology? Psychology? Macroeconomics? Critical theory? Supply-chain management? It takes a village to understand a village.

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## 2 Our Approach

Despite the challenges, the stakes with real-world problems of unsustainability are high. To fail to address wicked problems in sustainability, or to continue to fragment and oversimplify them as disciplinary problems, failing to bring all our lenses to bear on the problems, is to evade responsibility. (Ledford, 2015)

Our approach to meeting some of these challenges, in our first-year undergraduate living-learning community for engineering students interested in sustainability, has been to seek common denominators between disciplines, to look to the design process that so many engineering programs have at both the freshman and capstone levels of programs. Our program, called HERE (Home for Environmentally Responsible Engineering), was introduced at Rose-Hulman Institute of Technology in 2010. In addition to residential and co-curricular projects, speakers, and events, the HERE program involves a three-quarter-long sequence of special sections of courses required of almost all students at the school. Students in our program enroll together in a fall course on the global contexts of sustainability, a winter writing course, and a spring introductory design course. In foregrounding the design process, what we are really doing is seeking a common ground approach to interdisciplinarity (Repko, 2007; Newell, 2013).

In our first attempts, however, the spring design course arrived too late to be useful for students. The disciplinary affiliations of instructors in the fall and winter terms—both of them professors in the humanities—struck students as too far outside their own interests and budding professional identities. By the time students took part in the design process, they perceived it less as an integral part of their education in sustainability, and more as a part of their own professional training. To compensate for this problem, we tried moving the design course to the fall quarter, team-teaching it with faculty from the humanities and from engineering fields, integrating design and writing and stretching this course over two ten-week academic quarters into one twenty-week project. Predictably, now with hindsight, it is clear that teaching the design course before the global sustainability course would not afford students much awareness of context.

Our most successful attempt has come in the 2015-16 academic year, when we made the design process an important feature of all three courses. One reason for our relative success is that the sequence now moves from global (fall) to regional (winter) to organizational/campus sustainability (spring), which is built around a concentric model of sustainability. By the end of the sequence, students have a framework they can bring to bear on other problems, whether they're working within organizations or not. They have been taught to see organizational, technical, and professional aspects of environmentally responsible engineering as nested within their responsibilities as citizens and stakeholders in neighborhood communities and in local regions, and to see these professional and civic dimensions of sustainability as nested within the global biogeochemical and energy systems in which humans participate along with all other species. The model of sustainability as social and cultural systems functioning within the limits of planetary systems is underscored by our sequenced curriculum.

## 3 Interdisciplinarity of the Design Process

A more important reason for our success, at least for the purposes of this paper, is that we have made the design process the backbone of our curriculum. The design process is inherently interdisciplinary because it is a recursive method for framing, asking, reframing, and answering questions, a method common to most, if not all disciplines. As Allen F. Repko shows in his "correlation of models of the interdisciplinary process," theorists as diverse as Julie Klein, Bill Newell, and Rick Szostak depict a remarkably similar integrative program for problem-solving (Repko, 2006): Klein, Newell, and Szostak all suggest that interdisciplinary thinking begins with problem definition or question-asking, moves to determining which disciplinary "representatives and consultants, …models, traditions, and literatures," which "relevant concepts, theories, methods," "are particularly relevant to the question at hand. The next set of stages involves searching for alternative solutions, gathering knowledge, collating knowledge, comparing previous research, and then evaluating "results" as Szostak would say, "assumptions and concepts" as Newell would say, or the "adequacy, relevancy, and adaptability" of "all contributions" as Klein would say. And while the third set of stages is more varied, according to Repko for Klein, Newell, Szostak, and Repko, the interdisciplinary research process culminates with the testing of a "new understanding." Finally, despite the enumeration of these logical movements as "stages," Repko notes the iterative and non-linear nature of the interdisciplinary process: "along the way students should reflect on and may need to revisit, or even revise, earlier work" (Repko, 2006).

Note the similarities with engineering design. Students typically move from problem definition, to data-gathering and assimilation, to concept generation and evaluation, to modeling and testing and producing a design (Hyman, 2002). In the HERE Program, students are asked, and taught to ask questions like these: "What's the problem? Where does the problem come from? Who is it a problem for? How did it come to be a problem? What systems is it part of? From what natural systems does this problem seem to be a deviation?" And then questions like these: "How have others solved problems like this? At what point in the systems it takes part in could an intervention be made?" Learning from models happens in all disciplines, with models, examples, and prior art. In addition, our interest in interdisciplinarity encourages us to ask the second-order question of how these disciplinary models—problems defined as well as potential solutions sought—might be combined.

At both the problem and the solution stages, disciplinarity becomes evident: political scientists see political problems, while economists see economic problems, and while ecologists see species interactions as central, sociologists see human networks and systems as central. Technologists often hunt technical solutions to technical problems, while scholars in the humanities generally seek cultural and conceptual solutions to ideological and narrative problems. But recognizing this disciplinary is a strength. Recognizing disciplinarity means seeing how disciplines shape both problems and solutions. Transcending disciplines means being able to integrate them.

## 4 Impact

Framing our iterations of the design process as interdisciplinary process helps students understand a key aspect of problems of unsustainability. It helps them see there is no such thing as a single discipline that can answer all questions, because there is no single discipline or profession that can even ask all questions. It also helps them understand engineering. Student engineers often mistakenly think they will spend all of their time on the job "designing," but they don't always see the whole process, and they don't always understand the purpose of their work. If they can spend more of their time defining and redefining problems, we believe, following the lead of Cynthia Atman and Karl T. Ulrich, that they can be better engineers (Atman, 2014; Ulrich, 2011).

Preliminary feedback from students suggests that at least some of this is working. Here are four typical responses from our 2015-16 HERE class, self-reported at the end of their second quarter.

> "This project was the main thing that really cemented my confidence in do a design project. I felt that I learned a lot about the implications of our plans on the people we were trying to help and thought the focus on the stakeholders was very helpful to my understanding of the project focus. Throughout the project however, it seemed that there were a lot of unanswered question and that what was expected as for our class report wasn't always clear. As a design challenge I found this interesting and I would have found it fun to iron out the kinks and fill the uncertainties, but for the class project is was somewhat of a nuisance. Despite these small irritations I think the group experience was very good and that I am much more confident in my ability to work as a team to accomplish a design proposal."

> "I have seen the most improvement in the problem definition and solution in an environmental, social, and economic context section after having done the final project for this class. In the past 3 weeks, I have really learned to be more analytical in problem solving while taking into account the triple bottom line. When my group was writing the final paper for RH131, we took a lot of time to think through potential social, environmental, and economic problems while we designed the our [sic] energy efficient park."

> "This quarter has helped me with problem definition and accurately laying out issues. This in turn has helped me with seeing the impacts of decisions and being aware of the various side effects of any solution. I've also seen more variations in the definition of 'sustainability' in different contexts and fields, and I feel I've managed to obtain a more complete understanding of the topic and its many nuances."

> "By going from GS130 into RH131 I have been able to learn about sustainability in a different way. This has allowed me to get two perspectives and ways to think about sustainability topics. I have improved on my knowledge of the decision making process as a whole and how to handle it with a team."

> "I have never done this much group work in my life and I am actually enjoying it. I feel like I have learned a lot about written communication and visuals to display the design idea my team is presenting, but not as much about oral communication. I think I just need more practice and Intro to Design will help with that. One of the things I have seen the least improvement on is the implementation of the proposals we come up with. GS 130 had a theoretical project and in RH 131 was the first time I got to see a glimpse of what implementation was like through the professors and stakeholders from ISU and the Terre Haute community, but we never truly implemented the ideas while in the class. I'm really looking forward to the end of design when we have a full plan of implementation to change the campus for the better."

Full quantitative data are not available as of the date of publication, but preliminary results suggest small changes of attitude but dramatic changes of confidence in the design process. On questions that ask students to express agreement or disagreement with general statements about sustainable engineering, on a scale of 1-7, with 0=strongly disagree; 4=neutral; 6=agree; 7=strongly agree, students at the end of the year show as much general agreement as they did at the beginning. For the statement, "It is important for me to learn how engineers can make the world more sustainable" the average response at the start of the fall quarter was 6.3 (n=25), and at the end of the spring quarter it remains 6.3 (n=14; the lower value reflects some attrition and some incomplete responses). On the statement, "It is important for engineers to consider the broader potential impact of technical solutions to problems," the fall and spring averages were both 6.2. And on the statement, "Interdisciplinary learning is indispensable for my professional development," the fall average was 5.9, while the spring average is 6.0.

More useful, even with the currently low n value for the spring, is students' assessment of their confidence in design. In the fall, 4 out of 25 students felt 80-100% confident they could identify the environmental elements of an engineering project; by the end of the spring, 8 of 14 students expressed similar confidence. In the fall, 3 students out of 25 felt 80-100% confident they could identify the social elements of an engineering project. Today 12 out of 14 felt the same. Four out of 25 felt 80-100% confident they could recognize the social and economic impact of engineering design, which has risen to 11 out of 14. Finally and most importantly, in the fall, 6 out of 25 students felt 80-100% confident they could understand the meaning and application of sustainable engineering. As of today, 13 out of 14 students felt the same.

This growth in confidence, we believe, is a sign that we are on the right track.

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# A Product-Centered Approach to Circular Economy in Design Education for Engineers

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## Abstract

In a linear economy, manufactured products for consumption are central to prosperity and growth. The global material and energy flows resulting from this paradigm have, however, resulted in an unsustainable situation, with urgent issues, such as global warming and depletion of resources. In order to understand the consequences of consumption and as a tool to minimize its environmental impact, life-cycle thinking has been introduced for the manufactured products. This is needed to accurately and justly describe the total use of resources and their consequences.

Circular Economy aims to close loops of material flows in the society to reduce waste, among other things. These loops can be analysed in terms of mass flow, if you are interested in resource issues or logistics, but also in terms of, for example, energy use, cost or $CO_2$-emissions, as proposed here.

The objective of this paper is to explore a way to use the Eco Audit tool within the widely used CES EduPack educational software as a means to analyse these latter properties for manufactured products. Our approach is product-centered, rather than user-centered, and the product is specified through the Bill of Materials (BoM). Case-specific parameters, such as energy source used, transport modes and distances etc are given as inputs.

Here, examples are shown of how engineering students working with product development can investigate circularity already at the design stage, using the built-in database. The possibility to specify recycled fraction in the feedstock and degree of recycling at the End-of-Life enables basic studies of closed material loops. Eco properties of the product (energy use, $CO_2$-footprint) and cost are estimated and visualized for: Material production, Manufacture, Use and Disposal phases as well as Transports. It is concluded that the Eco Audit can be useful as a tool to investigate and discuss circularity in design education. Future challenges to include re-used materials or components in the Eco Audit are discussed as well as the separate development of a Materials Circularity Indicator (MCI) for mass-flow.

# 1 Introduction

## 1.1 *Circular Economy*

Closing loops of material flows in order to minimize waste is central to Circular Economy. A closed loop refers to the sustainable management of materials used in a product, where these are collected post-consumer to be recycled, remanufactured and/or re-used to make new products. In contrast, in an open loop, post-consumer material turns into waste. These loops can be analysed in terms of mass flow if you are interested in resource issues or logistics, but also in terms of, for example, energy use, cost or $CO_2$-emissions if you are interested in the consequences of the material flow.

In this paper, a way to use the Eco Audit tool in CES EduPack (hereafter referred to as *The Software*) is explored as a means to analyse these latter properties. It is based on a Bill of Materials (BoM) of a given product, some basic production data and product life scenarios (Ashby, 2013). One major characteristic of the approach is thus that it is product-centered. Moreover, the focus on energy use, cost and carbon dioxide emissions as the main three metrics of study means that it is very relevant to future engineering education. The method is streamlined, so that investigations can be conducted within the time-frame of a course assignment or classroom exercise and the software is already widely used for materials-related teaching in Science, Engineering and Design. This makes it a suitable platform that can be used to introduce life-cycle and circularity thinking to important groups of students.

Independently, Circular Economy metrics for product-centered performance evaluation have recently been developed for use in industry (EMF, 2015a). They include a Material Circularity Indicator (MCI) that proposes a quantitative assessment of the circularity of a product and the tracking of progress towards circular design. This approach is more explicitly concentrated on mass flows which may help engineering students to explore the circularity concept with a complementary focus. Examples of educational areas are: constrained resource awareness, *Design for Sustainability* or as introduction to *Product Life-cycle Management* (PLM). The MCI is presented briefly at the end of the paper in the hope of stimulating discussion and feed-back from the Engineering Education community.

## 1.2 *Life-cycle thinking*

In Design education, life-cycle thinking is normally used in a linear cradle-to-grave context to assess and minimize, for example, energy use or emissions over the product life-cycle. In many cases, the flow of materials has followed an open-loop or “take-make-use-dispose” pattern, where materials are transformed into products to be discarded after use, as indicated for a car in Figure 1. The main life phases are: (i) *Material production*, (ii) *Manufacturing*, (iii) *Product use*, and (iv) *Disposal*, with the important additional contributions from *Transports*.

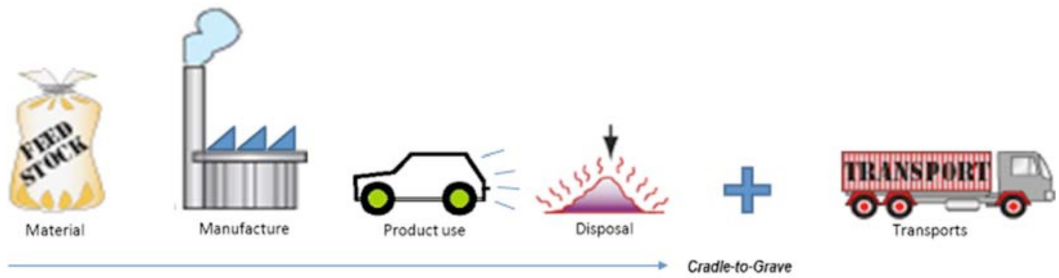


Figure 1: Phases of a linear cradle-to-grave product life-cycle, considering: Material production, Manufacture, Use and Disposal, as well as Transports associated with the product (a car, in this case)

These phases can be visualized using an Eco Audit to give an overview of their impact (Ashby, 2013). In Figure 2, energy use and estimated cost are shown. $CO_2$-footprint (not shown) mimics the energy.

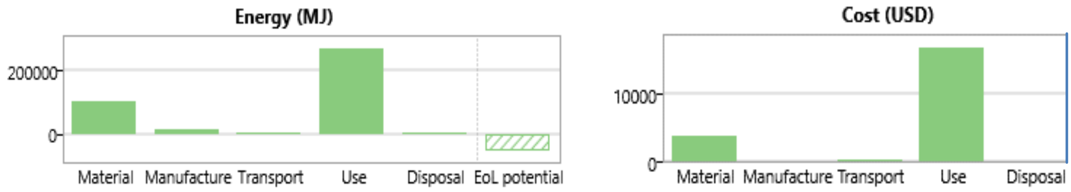


Figure 2: *Visual example for a car: Materials production, Manufacture, Use and Disposal, as well as Transports*

An Eco Audit can represent the cradle-to-grave impact during a single use of a product. However, in order to analyse a closed loop, cradle-to-cradle properties have to be considered, which is also possible to some extent via recycled feedstock materials and End-of Life (EoL) options.

In the Eco Audit, there are six EoL options to account for the *Grave* side of the product life-cycle. These are indicated for the car in Figure 3. The recovery of energy and $CO_2$-footprint reductions that come as a result of recycling or re-use are indicated as a *maximum EoL potential* in the tool. The Eco Audit calculates the EoL potential as the energy or $CO_2$ 'credits' that could be realized in future life cycles by using the recovered material and thus avoiding the use of virgin material. This is a net value, and takes into account also the energy requirements and $CO_2$-footprint of the EoL process itself (for instance, the $CO_2$ released during combustion for energy recovery).


Figure 3: *Illustration of the different End-of-Life strategies available in CES EduPack (Ashby, 2013)*

The main use of this life-cycle tool, which is *not* for a Life-Cycle Assessment (LCA), but rather for a streamlined Life-Cycle Inventory (LCI), would be at the design stage of product development, where different scenarios can be considered and compared. Since the database of the software contains both materials data and manufacturing process data, it may also be useful to explore options for production.

## 2 Product-Centered Circular Materials Economy

In design education, it is relevant to consider circularity already in the decision-making at the design stage. Circular Economy in a user-centered perspective can conceptually be described using the traditional butterfly diagram (EMF, 2015b), of which the technical half is displayed in Figure 4.

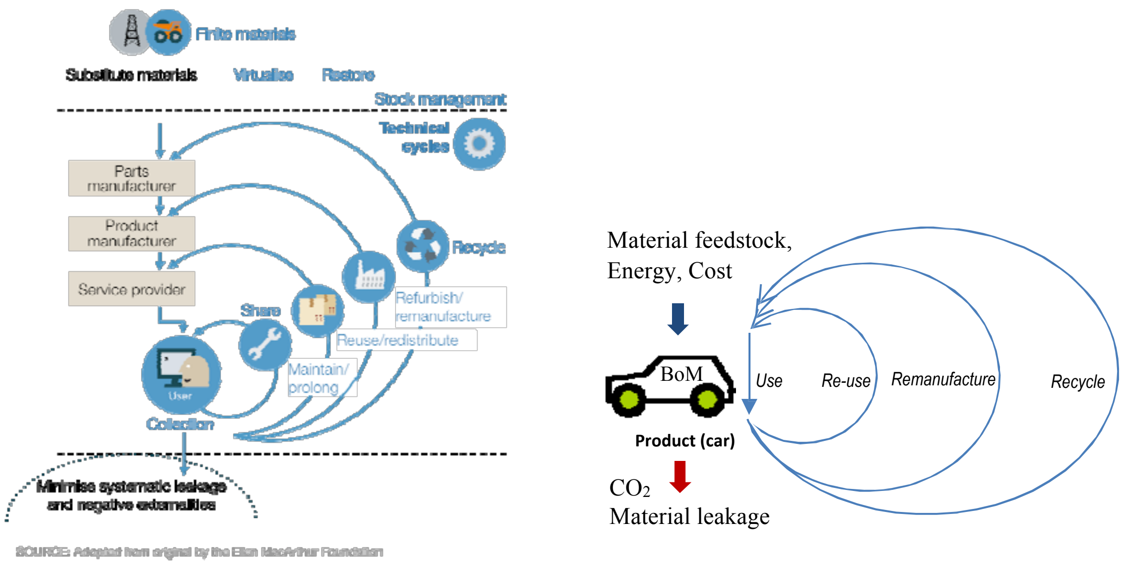


Figure 4: Traditional Butterfly diagram of Circular material flows (EMF, 2015b), centered around the consumer/user (left) and a product-centered diagram for a car, with EoL options (right)

In this established model, materials constitute a valued asset to be conserved for re-use (Webster, 2013). It implies the use of renewable energy, material tracking (quality and location), and designing products that aid with the material recovery and re-use. A manufactured product and its parts hence need to be considered over several consecutive or alternative life-cycles. These should cover maintenance, remanufacturing (repairs and upgrading) in order to prolong use, or simply re-use.

In a product-centered analogy to the Butterfly diagram, the schematic components of a circular materials flow for a car can also be seen in Figure 4. In addition to the loops, material flow for maintenance of the car (not shown) should also be considered in the design. Some materials, *e.g.*, tires, thus need to be added as they represent maintenance. Replaced parts may be re-routed (recycling or re-use).

An additional benefit to the materials database and the software used in this paper is that it contains information of a material's composition and recyclability as well as, for example, toxicity or criticality (EU or US critical lists) of its elements. This is relevant in the consideration of limitations to circularity.

## 3 Eco Audit Examples

The Eco Audit tool can help visualize the four life-cycle phases (plus transports) and estimate eco-properties using assumptions and models detailed in the software. The product is specified through the BoM, as shown below (see Figure 5). The case-specific parameters, such as mode of energy use, transport modes and distances, country or region of use (affecting the energy mix etc.) are given as inputs, partly supported by drop-down menu options. Cost and secondary processes are available only in the enhanced Eco Audit. The examples below are made using the standard Eco Audit.

### *3.1 Family Car BoM and Maintenance*

This first example is from a BoM of a family car, based on data from a sample Eco Audit project file that is included with the software in a folder stored together with the program files, slightly adapted from Ashby (2013). There are a number of other ready-to-use Eco Audit Project files: PET or glass bottles, domestic irons, space heaters, toasters, electric kettles and even a wind turbine, that can be utilized as a starting point for teaching or assignments. The family car shown here represents an adequate level of complexity as an educational case.

Material, manufacture and end of life

| Qty. | Component name | Material | Recycled content | Mass (kg) | Primary process | End of life |
|---|---|---|---|---|---|---|
| 1 | Steel content | Low alloy steel | Typical % | 850 | Rough rolling | Recycle |
| 1 | Aluminium content | Cast Al-alloys | Typical % | 438 | Casting | Recycle |
| 1 | Thermoplastic content (PU | Polyurethane (tpPUR) | Virgin (0%) | 148 | Polymer molding | Landfill |
| 1 | Thermoset content | Polyester | Virgin (0%) | 93 | Polymer molding | Landfill |
| 1 | Elastomer content | Butyl rubber (IIR) | Virgin (0%) | 40 | Polymer molding | Landfill |
| 1 | Glass content | Borosilicate glass | Typical % | 40 | Glass molding | Recycle |
| 1 | Other metal content | Copper | Typical % | 61 | Extrusion, foil rolling | Recycle |
| 1 | Textile content | Polyethylene (PE) | Virgin (0%) | 47 | Polymer extrusion | Landfill |

Figure 5: Sample Bill of Materials in Eco Audit for a family car with data adapted from Ashby (2013)

We assume delivery by sea freight from Japan to the UK and the car has a life of 10 years with low daily use in the UK (20 km during working days) in this and the following case. All components that are possible to recycle are done so after the 10 years. The $CO_2$-footprint for the family car with moderate use is given visually in a Summary Chart (see Figure 6). Associated energy use and cost have already been shown as the example in Figure 2 above. The Summary Charts represent a snapshot of one life-cycle where improved design, re-design or improvements in manufacturing processes can be made by students guided by the visual features. In the case of a family car, light-weighting or a different fuel are examples of how to reduce impact from the dominating use-phase. Materials necessary for maintenance can be visualized together with the product and in this case, one could elaborate on effects of increased maintenance, leading to increased lifespan, for example.

Product information

Name: Maintenance

Material, manufacture and end of life

| Qty. | Component name | Material | Recycled content | Mass (kg) | Primary process | End of life |
|---|---|---|---|---|---|---|
| 2 | Sets of Tyres | Butyl rubber (IIR) | Virgin (0%) | 40 | Polymer molding | Landfill |
| 1 | Windscreen | Borosilicate glass | Virgin (0%) | 10 | Glass molding | Recycle |

Transport

| Name | Transport type | Distance (km) |
|---|---|---|
| Imported from South Kore | Sea freight | 1e+04 |

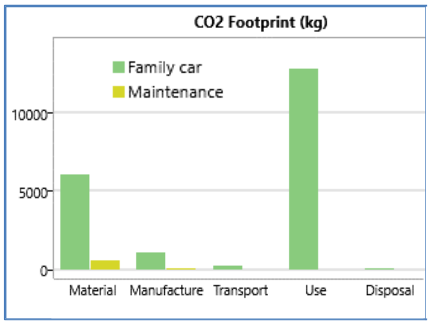


Figure 6: Example BoM for maintenance (left) and comparative Summary Chart from Eco Audit (right).

One has to be aware, and emphasize to students, that eco-data in general and cost data contain relatively large uncertainties in the absolute values (Ashby, 2013). However, if the uncertainties are small in comparison to the main features of the diagram, they can still be useful, in particular, in this educational context. Numerical data is given in a detailed report accessed directly from within the software. This report also has additional diagrams summarizing different life-cycle aspects.

## *3.2 Feedstock options*

The built-in ‘Compare with’ function of the software can be employed to introduce alternative or sequential scenarios into the bar charts, as shown in the next example. The same Eco Audit project file included with the software was used as a starting point to investigate the effect of *recycled* or *virgin* feedstock. Figure 7 shows the family car comparing three different purely hypothetical feedstocks, from all virgin to all recycled.

The first case uses feedstock of typical recycled content, available as a drop-down option within the Eco Audit. This is the reference case (see Figure 7). The second case uses feedstock of virgin materials and the third case uses 100% recycled feedstock, where possible. The energy use and the $CO_2$ footprint in the Eco Audits show very similar pictures, therefore only the latter one is displayed.

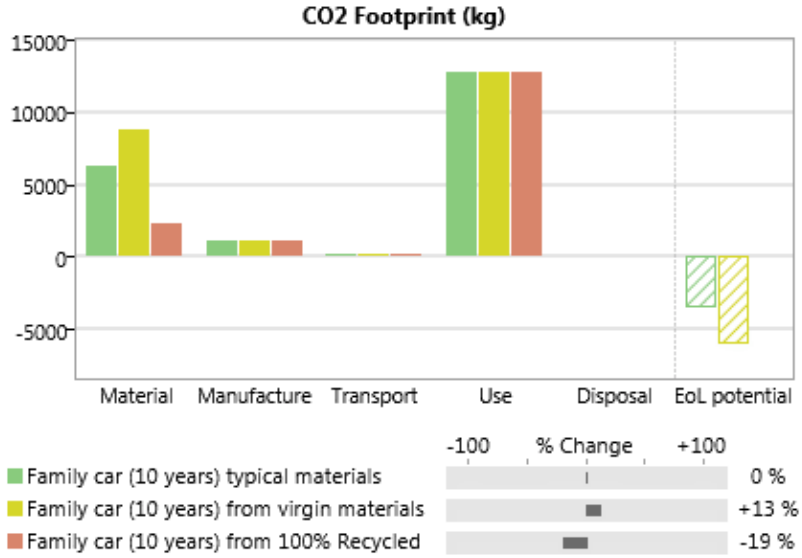


Figure 7: Comparison of a new car made from different feedstock (typical, virgin, or 100% recycled).

As expected, even with a moderate daily distance, the use phase is the dominant one. The influence of the feedstock is, however not negligible and it shows that virgin materials in this example could cause three times more $CO_2$-emissions (or use around three times more energy) than 100% recycled feedstock.

### *3.3 Mineral water bottle comparison*

The Eco Audit can be useful also to study options with different degrees of circularity (ResCoM, 2016). In the third example (see Figure 8), a much simpler product, a mineral water bottle (container, cap, liquid) was used to illustrate how a mainly linear system (PET bottle) can be compared to a circular (glass bottle).

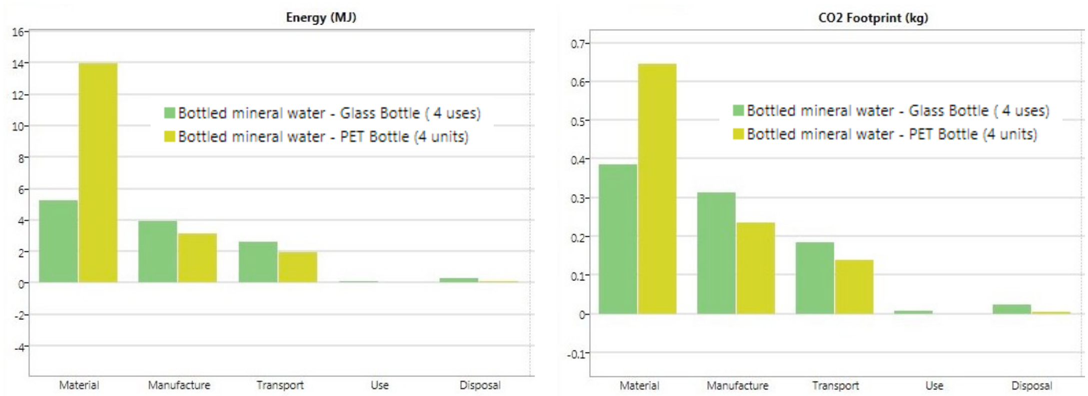


Figure 8: Energy use and $CO_2$-footprint showing that re-use is considerably more favourable

The function compared is 4 litres of mineral water delivered by either 4 Virgin PET bottles that are 50% recycled at EoL *or* 1 glass bottle made by 80% recycled feedstock, that is re-used 3 times after first use and then recycled at the EoL. The Eco Audit shows that the PET bottles use around 50% more energy and that the material phase is by far the most dominant contributor. By re-using material, the potential energy savings are significantly better than what is possible by recycling feedstock (*e.g.*, the car case). This is consistent with the observation that tighter cycles, as shown in Figure 4, are more desirable.

## 4 Material Circularity Indicator

For investigations and discussions around mass flows, the recently developed *Material Circularity Indicator* (MCI) may be used at the product level to assess how closed the loops of a product are in the context of a circular economy. This can be evaluated at the design stage as a complement to *energy* use, *$CO_2$-footprint* or *cost* from an Eco Audit, but would also be useful in order to optimise the manufacturing process in terms of circularity. The MCI was developed for decision-making in industry, however, with students it may serve as a platform for circularity discussions.

Specifically, the MCI measures the extent to which a product has minimised the amount of virgin material as feedstock and unrecoverable waste at end of life, as well as how long and how intensely it is used compared to the industry average (EMF, 2015b). The comparison with industry is because the longer a product is used, and the higher the rate it is used with (for example a shared product) *versus* the average values, the less material is used over the same period of time.

The equation for the MCI of a product, *p*, is:

$$MCI_P = 1 - \frac{V + W}{2M + \frac{W_F - W_C}{2}} \cdot F(X)$$

where V is the fraction of feedstock from virgin sources, W is the unrecoverable waste fraction calculated from the waste going to landfill, which also considers the average amount of waste generated in the recycling process $W_C$ and the waste generated to produce any recycled content used as feedstock $W_F$. M is the product mass. F(X) denotes how the lifespan and intensity of the product compares with the industry average, and for this example, we are assuming it is the same (EMF, 2015b).

MCI values range from 0 (zero) to 1. The higher the MCI score, the better the materials of the product circulate. This value can be used as a tool to improve the sustainable and efficient use of materials in products, for example in courses on product development and/or design for sustainability. For more information on this indicator, background and theory behind the calculations, a paper is freely available (EMF, 2015a). There is also an interactive Excel tool for calculations of the MCI that can be explored available from the same website. The MCI tool was applied to the mineral water bottles example above (section 3.3). Re-used bottles give much higher MCI (see Figure 8), consistent with the lower energy use, found independently by the Eco Audit of section 3.3. The MCI looks at systems and considers only mass, whereas an Eco Audit considers the specific footprints of the actual materials.

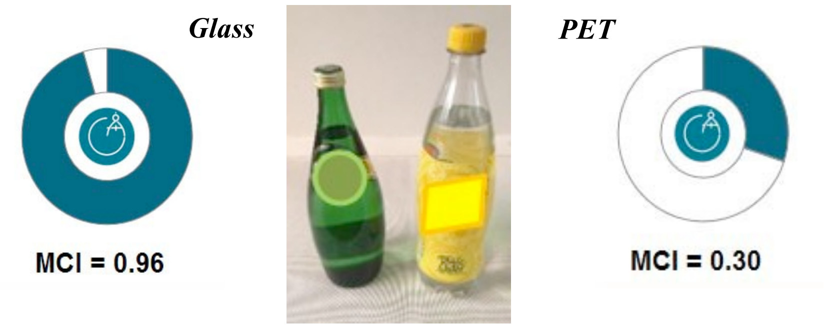


Figure 9: Comparison of MCI for *glass* or *PET* water bottle options considered in Eco Audit above.

## 5 Summary and Conclusions

In this paper, examples are shown of how a standard engineering and design software can be applied to study relevant aspects of circularity around a product. Materials and manufacturing details are taken from the embedded database or are given as input, whereas energy use, $CO_2$-footprint and cost are estimated and visualized in summary charts generated by an Eco Audit.

Our approach is product-centered and display the consequences (energy use, $CO_2$-footprint) of material use in the product, rather than the material flows themselves. The circularity can be explored, to some extent, via the BoM.

For study of materials flows, an industrial materials circularity indicator have been suggested. This is also a product-centered model and may be used at the design stage but also when considering production systems for circular economy.

Future challenges include exploring ways to introduce re-used materials or components in the Eco Audit, perhaps trying to represent maintenance better in the BoM and, finally, it would be useful to take functional units into account for fair comparisons of circular options.

It is concluded that the Eco Audit can be useful as a tool to investigate and discuss circularity in design education and the Authors are interested to discuss the value of the proposed Materials Circularity Indicator (MCI) as a complementary way to study mass flows in production systems.

## Acknowledgements

The authors are grateful for funding by Production Technology West at University West (Trollhättan, Sweden). All Eco Audits were produced by EduPack 2016 licensed from Granta Design Ltd, Cambridge.

Fruitful discussions and collaboration with Dr Ana Pereira is gratefully acknowledged.

The development of the Materials Circularity Indicator was a result of the Life+ projects in collaboration with the Ellen MacArthur Foundation. The ResCoM project has contributed to its insights. The project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 603843

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# The E-Waste Academy for Scientists; Integrating Interdisciplinary and Global Dimensions for E-Waste Researchers

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## Abstract

Since 2009 United Nations University and its partners through the Step Initiative have run a graduate level program aimed at supporting interdisciplinary and global dimensions to e-waste related research. This paper presents the aims and motivations for undertaking this initiative and details the history of the event. It also explains how the event is programmed with the objective of achieving its aims which includes complexity activities, group work, expert lectures, study tours, panel discussions, participant presentations and a social program. Feedback from the participants is overwhelmingly positive with a large majority indicating that the overall experience was “outstanding” and in particular the development of a network, the motivational and “ideas” impact on their work & the international dimension are identified as key benefits.

## 1 Introduction

The issue of e-waste is a perfect example to demonstrate the need for a sustainable transformation in the approach to engineering education. Due to an explosion in consumption of ICT and other business and household devices which bring many social and economic benefits to their users, it is the fastest growing waste stream in the world. However, it contains numerous critical raw materials whose value is lost due to low collection rates and poor material processing practices highlighting the necessity for it to become part of a more circular economy. Likewise, it is highly toxic if treated incorrectly but nonetheless a real source of economic opportunity in developing countries, making greater stakeholder engagement essential to develop sustainable solutions.

Taking this into account the United Nations University and a number of its partners through The Step Initiative have developed a graduate level workshop entitled The E-Waste Academy for Scientists (EWAS) which brings together post graduate students from across the world engaging with e-waste from a wide range of disciplines, including engineering.

Starting in 2009, it has ran on 5 occasions to date with the next iteration planned for August 2016.

- Netherlands/Belgium [2009, 2010, 2011]
- Switzerland [2013]
- China [2014]
- Limerick [2016]

The typical participation is 20 students per EWAS across social and physical sciences giving an alumni of roughly 100 graduates from top universities across 30 countries and 6 continents.

This paper will give a detailed overview of how the EWAS sets about to achieve its aims, provide reflections on the strengths and weaknesses of the model, detail feedback from the participants and give opinions on how it may develop in the future.

## 2 EWAS Aims

The EWAS vision is to be the foremost forum available to young researchers involved in e-waste and to look at e-waste in its entirety rather than through the lens of an academic discipline.

It aims to

- Share existing knowledge and research → link young researchers to experts from industry, academia and projects on the ground
- Exploit synergies of multidisciplinary research → develop a network of young scholars
- Enable capacity for high quality scientific research → develop key skills for young researchers

During the EWAS, students have an opportunity to present their work on e-waste from their own disciplinary perspective and have it questioned and interpreted by others from different backgrounds. They participate in an intensive set of workshops, group work activities, academic, industry & policy lectures and study visits.

## 3 Creating the right environment for interdisciplinarity & systems thinking

Considering such aims it is vitally important to program the activities of such a compressed event to help achieve them and everything about the EWAS is purposely designed to do so. This section will provide an overview of how this is achieved

### *3.1 A Diverse Network*

Clearly the requirement for students to experience different disciplinary and global perspectives requires a diverse cohort of students. Therefore it is necessary to disseminate the call for applications as wide as possible ensuring that they are reaching universities around the world and across the disciplinary landscape. Students are required to submit an application which includes a personal statement about why they want to attend the EWAS and what they think that they can bring to it. They are also asked to supply a paper on their research topic. These are carefully vetted to ensure that the correct mix of students gather for the event. From the past 5 events, the 91 alumni come from 30 countries, and the next edition in 2016 in August is set to add another 20 students to the alumni network, further expanding the geographic diversity across 35 countries.

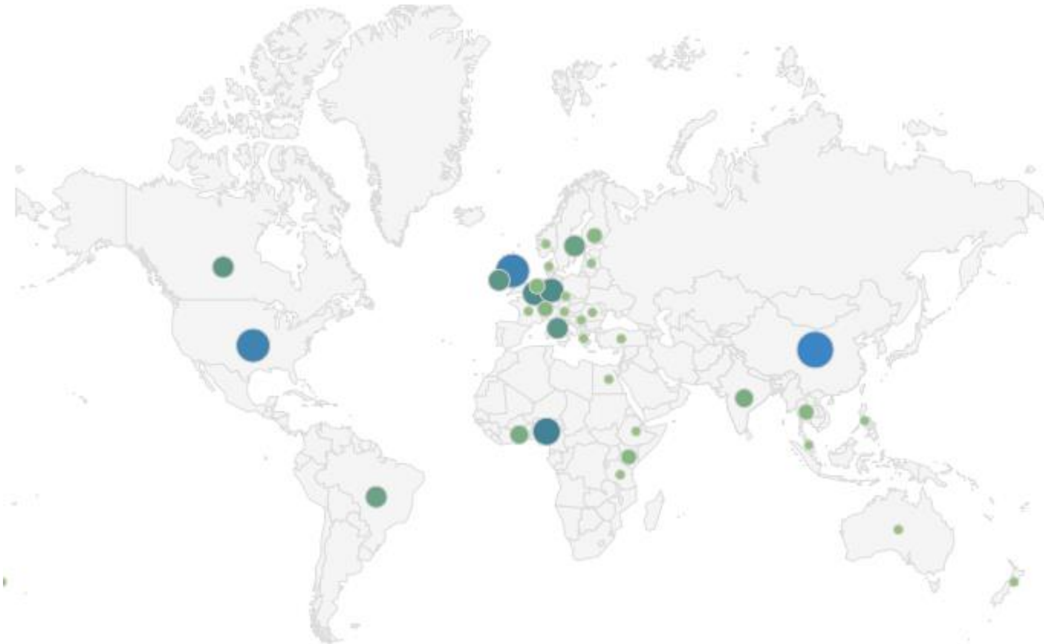

Figure 1: Geographic distribution of EWAS participants

Figure 2: Students from around the world and across the disciplinary spectrum.

## *3.2 Simulation Games*

To bring an element of fun and bonding, EWAS regularly uses board games as an ice-breaker for students but also as a thought starter for the interdisciplinary theme for the week. For example, The Perspectivity Challenge is a team based board game which creates a lesson from experience in the dynamics of complex issues and puts its players in the shoes of key decision makers. During a powerful debriefing session players are forced to consider how their actions are perceived by and affect other parts of a complex system. Likewise, “In The Loop” employs game-based learning techniques to illustrate the interconnectedness of today's economic, environmental, political, and social challenges by combing these different approaches to resources into one broader, 'macroscopic' perspective. This serves as an excellent way to for students to internalise this message and be able to apply it during the rest of the EWAS.

Figure 3: Carefully designed games highlight the challenges of complex systems

### 3.3 Expert Lectures

EWAS brings invited lecturers from industry, academia and government to provide expert insight into issues associated with E-Waste. These experts typically stay for much of the event and giving participants access to develop deeper conversations about their own research topics and the wider e-waste picture.

### 3.4 Hands-on Workshops

An essential pillar of the EWAS, there is always a hand-on workshop, requiring participants to work with their hands literally. The programme has included dismantling sessions focussing on consumer electronics as well as IT products in a real factory setting on actual dismantling stations, to give participants a feel of real world challenges and trade-offs faced by recyclers downstream, as well as designers and product manufactures upstream. Another hands-on workshop included a sampling analysis at a large recycler in Europe, including sorting and separating material from mixed pallets received from collection centres into various product categories and documenting the weights, brands etc.

Figure 3: Hands-on workshops such as the dismantling workshop provide academics with real world experiences – in this case about materials, design and dismantling challenges".

### *3.5 Groupwork*

The groupwork part of the curriculum is one of the most important and rewarding parts of the EWAS. The participants are divided into carefully selected groups to ensure diversity of subject and geography. The groups are then posed with problems which will require them to collaborate across these different perspectives in order to develop well-rounded and satisfactory solutions. The groupwork runs over the course of the entire week with dedicated sessions allocated to working together each day. It culminates with a presentation to the wider group followed with a comprehensive discussion. The groupwork deliverables in the past have included the participants constructing and conducting a public workshop at the World Resources Forum in Davos, designing and conducing an e-waste focussed role-playing game at the Basel Convention Secretariat and developing teaching case studies on e-waste.

### *3.6 Study Tours*

Study tours have proven to be a very popular aspect of the EWAS and enable students to see parts of the WEEE system that they have only previously read about. Examples of typical sites visited include smelters, recycling plants, refurbishment facilities and ports.

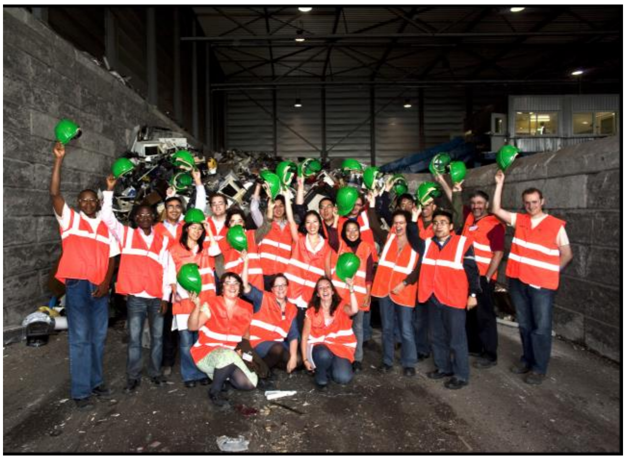

Figure 4: Site visits enable insights that desk studies can never truly deliver

### 3.7 *Panel Discussions*

A feature of the event has been a panel discussion which provides an overview of the e-waste situation in the host country. These are typically attended by representatives from government departments, producer responsibility organisations, enforcement agencies and port authorities.

### 3.8 *Student Presentations*

Each student also has the opportunity to make a presentation in their area of specialization within e-waste. For many it is the first time to present outside of a discipline specific context and presenting to a wide audience challenges students to frame their work within a broader context which is one of the key aims of the EWAS.


Figure 5: Presenting to a wide audience challenges students to frame their work within a broader context.

### 3.9 *Social Program*

The social program is also a carefully considered aspect of the EWAS in order to create the right environment for participants to learn from each other in a non-formal situation and also to enable participants to create friendships and an enduring network. It also builds some free time into the program to allow participants to explore the host city and to have a cultural experience.

Figure 6: The social program supports longer conversations and helps to build an enduring network

## 4 Participant Feedback

Detailed participant feedback has been gathered each year since the inception of the event with the results for overall experience presented in Figure 7. As can be clearly observed the feedback is overwhelmingly positive and gives great encouragement that the program is going some way towards meeting its aims.

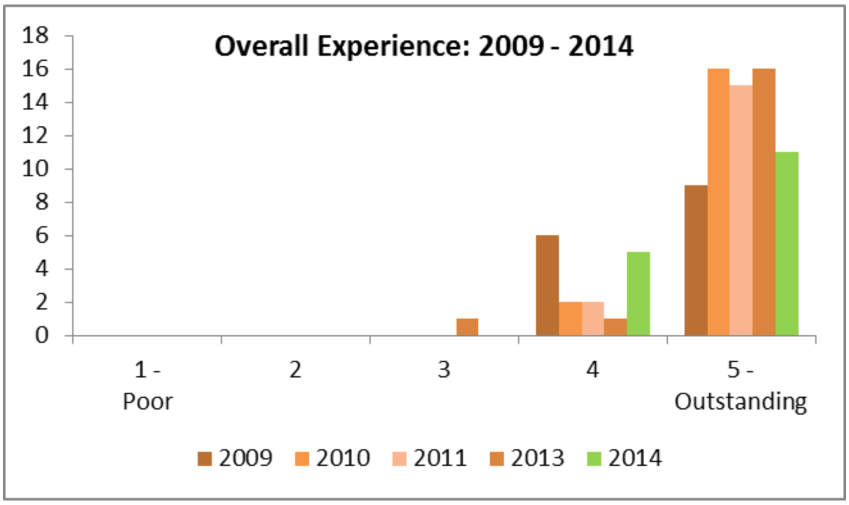


Figure 7: Participants rate their overall experience

Qualitative statements are also gathered during the collection of the feedback and a representative sample are given here. Recurring themes include 1) the development of a network 2) the motivational and "ideas" impact on their work & 3) the international dimension

- a good **network** of young scientists with some opportunities to work together somehow in the future
- new **friends**
- lots of **motivation** and new ideas to continue my work"
- The **innovative ideas** of solving the e-waste problem in my country.
- New research area on e-waste
- The **Friendship** and the potential **international networking** and collaboration.
- "A new network of **friends**/colleagues/companions
- A **world view** of research into e-waste
- A renewed **motivation** for my research

## 5 Conclusion

Since 2009 United Nations University, with partners through the Step Initiative have pioneered an interdisciplinary and globally oriented educational program aimed at graduate level researchers with the aim of helping to de-silo e-waste research. Over the course of 6 iterations of the E-Waste Academy for Scientists the feedback indicates that this is being successfully achieved. It would be of great interest to conduct follow up interviews and questionnaires with alumni from the event to assess the long term impact of the event.

# 'Advanced Design for Sustainability - reflection upon a new teaching approach'

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### Abstract

This paper reports upon and discusses a new teaching approach for the course 'Advanced Design for Sustainability' within the educational master program of product development, faculty of design sciences, at the University of Antwerp. The course of Advanced Design for Sustainability persuades a basic training of ecodesign, in which the general principles are educated, and tools and strategies related to ecodesign are discussed. The aim of this advanced elective course is to extend the students' knowledge related to ecodesign and to apply it in practice. In cooperation with a company, a concrete case will be elaborated. Afterwards, the students are asked to generate sustainable solutions to the offered problem.

To achieve the highest results, a new teaching approach was developed, in which an industrial company is working together with a group of master students with the aim to solve one sustainable issue, using some defined idea generation techniques. In order to offer a variety of contexts and problems to the group of students, the course is split into different half day lessons, each focusing on a different company. Each lesson is based upon a rigid and verified structure, consisting of four parts: (1) problem definition, (2) idea generation, (3) idea evaluation and selection, and (4) implementation.

In addition to the explanation of the new teaching approach, we report in this paper also upon the strengths and opportunities of the teaching method, and discuss the threats for all parties (teachers, students and companies). In short, the added value for participating companies: (a) they achieve a minimum of twenty wild goose concepts that can be used for further internal discussion, (b) they achieve a better understanding of the capabilities of master students product development, which might become their future employees.  Students learn, in these short half day exercises, both dealing with sustainable issues in companies and learn practicing ideation tools. An extra added value for master students is that they achieve in-house information of some companies, which can influence their career development interests. For teachers: organizing this type of courses is no extra effort for teachers, as instead of writing and optimizing a theoretical schoolbook, effort is put in contacting companies, discussing the most appropriate problems and choosing the right ideation tools.

## 1 Introduction

Ecodesign or Design for Sustainability is a discipline within product development in which the focus is put on the eco-impact of products and in which the full product life cycle should be considered (starting at choice of materials, production and assemblage, distribution and packaging, product use phase, and the end of life). Having the aim to go from a linear to a circular economy and reuse or recycle as much material as possible (Van Doorsselaer & Du Bois 2015). It is crucial to inform future product designers about the ecological problems and educate them how they can minimize the impact of products if we consider that 80 % of the environmental impact of  product is determined in the design process (Design Council 2002). Consequently, Ecodesign is one of the standard courses that is embedded in the bachelor curriculum of Product Development at the faculty of Design Sciences, University of Antwerp. In this course the environmental problems are educated and general principles for ecodesign are learned. Attention is put on the different eco-analysis tools, design guidelines towards more sustainable products, and the most used terms and strategies related to ecodesign. This theoretical course is supported by several practical design courses in which students have to apply their knowledge to design products with a low environmental impact. However, for those students who are interested in learning more, an Advanced Design for Sustainability course is organised as an elective in the master curriculum of Product Development. This 3ECTS-course aims to extend the students' knowledge related to ecodesign and to build experience with applying it in practice.

This paper describes and reflects upon the new teaching approach that is currently used since 2010 in this 'Advanced Design for Sustainability' course. As the course transcends the basic training of ecodesign, the aim is to apply the general principles, tools and strategies in a real industrial context and extend the students' knowledge related to ecodesign by learning new tools. Because of the complexity of dealing with sustainability problems, the students should learn facing the very different challenges and develop the ability to monitor the whole. Sustainability is not just about environmental benefit but also about useful products and added value. As discussed by Nyström Claesson and Svanström (Nyström Claesson & Svanström 2015), handling complexity becomes more and more urgent in order to manage climate change, increased levels of chemicals in society, conversion of the energy system, food and water supply and many other challenges. To be able to act in a relevant way, students need to develop skills such as systems thinking to be able to assess complex systems. Systems thinking for sustainable development has been described as "the ability to collectively analyse complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks" (Wiek et al. 2011).

The elective has been highly useful as a platform to pilot new ways of teaching engineering for sustainable development, as we wanted to challenge our students to develop a critical understanding of sustainability. Currently, a new teaching approach was developed, in which an industrial company is working together with a group of master students with the aim to solve one of their ecodesign issues, using some defined idea generation techniques. In cooperation with a specific company, a concrete case will be elaborated. This allows our students to consider the complex environment in which the problem is situated (on level of technology, economy, social and environmental aspects). Afterwards, the students are supported to generate sustainable solutions to the offered problem. Our objective in this paper is to illustrate how such a new approach works in practice and how it has helped students to develop a more critical, systemic perspective on sustainability. Lastly, in the paper, we also reflect on the advantages and disadvantages for all involved stakeholders.

## 2 Detailing the teaching approach

### *2.1 Structure of the course*

The course is structured in six separate lessons. From which three different lessons are focussing on testing and experiencing new tools such as biomimicry (Benyus 1997; the Biomimicry Institute n.d.), SIS toolkit (OVAM 2012), Design with intent (Lockton et al. 2010), etc. The other lessons are considering a concrete case elaboration. In order to offer a variety of contexts and problems to the group of students, each focusing on a different company. Each lesson is based upon a rigid and verified structure, consisting of four parts: (1) problem definition, (2) idea generation, (3) idea evaluation and selection, and (4) implementation. Each lesson takes about four hours and case elaboration always needs some homework in order to finish the idea implementation part (explained further in the Section below). The course is evaluated using permanent evaluation, taking the students' participation and the ideations' results into account).

## 2.2 *Detailing one specific lesson*

Each sustainable-ideation lesson is structured in the same manner using the Idea2Market-toolbox (Dewit & Du Bois 2009). This toolbox structures the ideation using four phases: (i) a problem definition phase, (ii) an idea generation phase, (iii) an idea selection and evaluation phase, and (iv) an idea implementation phase. The toolbox aims to facilitate the ideation process by suggesting to use specific tools in each phase and by indicating the assets and competences that are of importance. Within this framework specific advanced ecodesign tools were selected to increase the students' knowledge.

Important to notice is that as we (teachers) always prepare the lesson together with the company during a preshoot-session. Because every ideation has a different focus, complexity, level of detail, etc., the toolbox suggests to prepare each ideation in a preshoot-ing phase. The aim of the preshoot is not only to get to know the company better and to understand the problem, but also to decide which tools are the most relevant for the problem and for the students. For each phase, a maximum of two or three different tools are selected. The structure of each ideation is visualized in a template, as shown in Figure 1.

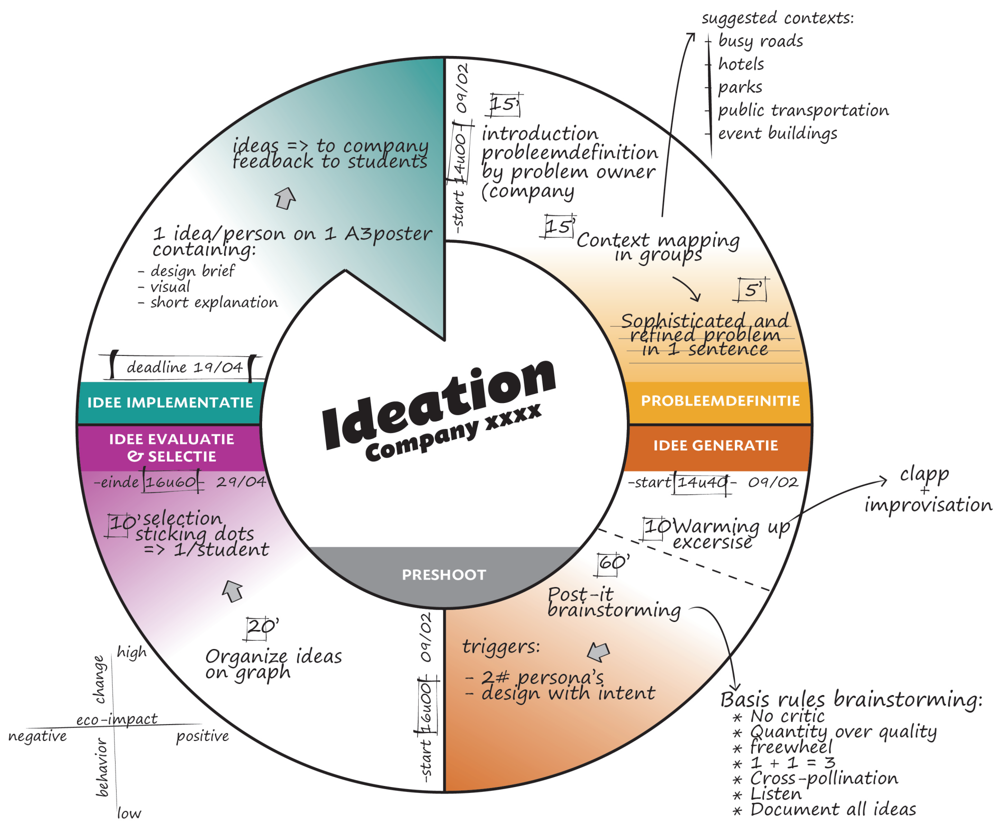


Figure 1. example ideation-case filled in on the standard template during the preshoot phase

In short, the 'Problem Definition'-phase, aims to support the students to clarify and boundary the problem. Often collection of information and creation of a reference model are two crucial steps to be able to define a common problem statement. At the end of the phase, the students should be able to formulate together a single sentence in which the problem or opportunity for their case is detailed on a sufficient level. Ecodesign tools that are important to consider in this phase are all eco-analysis tools, both quantitative and qualitative, as a source to explore the problem. Next to this, context mapping and system mapping tools are also used in order to be able to capture the complex problem, to keep the overview and to visualize the relationships among the actors.

In order to empty the students' brain and activate a non-school mentality, we organize a special warming up exercise in between problem definition and idea generation. The exercises are inspired on improvisation theatre and force students to act unnatural and spontaneous. Depending on the type of students and the problem definition, we force them to play the clap-game, play name games, or make free associations with gestures (Johnstone 2012).

The next step, the 'Idea generation'-phase is the phase that is standard characterized as brainstorming. However, brainstorming is only one of the idea generation techniques that can be applied to generate as much ideas as possible, without judgment or evaluation. To upgrade the level and number of ideas, extra tools can be used to get more inspiration. Related to ecodesign, we often use tools such as biomimicry (ask nature (the Biomimicry Institute n.d.)), eco-triggers, eco-heroes (narrowing 'what would x do?' (Jarvis 2009)) in order to trigger ourselves to think outside the box or to approach the problem from a different perspective. Qualitative eco-analysis tools (such as checklists (Wimmer 1999), Eco-Star (Van Doorsselaer 2009), LiDS wheel (Brezet & van Hemel 1997)) are also used in this phase as they also offer triggers for optimization.

The mass of all ideas should be taken into the next 'Idea Evaluation and Selection'-phase, in which they will be evaluated and the best ideas will be selected. Based upon the criteria that were formulated in the first phase, an underpinned evaluation and selection can be carried out. To support this phase, different selection tools can be used, nevertheless it is important to use multiple aspects of the environmental impact as selection criteria.

Lastly, the Implementation-phase has the objective to insure further succession and monitoring of the best ideas. Communication of generated ideas is crucial and the creation of a buy in of those people in the company that have the power to succeed is necessary. This can be achieved by visualizing the ideas, using different platforms. Next to communication, the implementation phase also supports people to thoughtful motivate the idea. Ecodesign tools that show the potentials for improvement (such as the Eco-star) can be used as argumentation.

## 3 Reflection and discussion upon the educational approach

In the past six years, 167 students have followed the elective. From the 15 opportunities, the elective Advanced Design for Sustainability is among the most popular electives. In this course, students of both first and second master students participate together. Students have to choose four electives over these two year period.

Reflecting upon the general approach using the Idea2Market toolbox with specific ecodesign tools, we experience two specific added values: (i) The communication among the different stakeholders (teachers and the industrial partners, but also with students) is straightforward and effective because a standard template is used to structure the preshoot-discussion, as shown in Figure 1. (ii) The selection and application of the different tools increase, for the companies, the guarantee for effectiveness. Simultaneously, students get practical experience with new specific tools. In general, we can conclude that the Idea2market toolbox is an efficient enabler for advanced design for sustainability. The additional approach of adding warming up tools is evaluated positively by all stakeholders. Although both students and company initially behave aloof, after the seriousness of the teachers all students and most company people overcome their fear to act different. This change of behavior has a positive effect on the students' behavior during the idea generation phase.

Reflecting upon the type of companies that are willing to participate in the course, we found that companies only participate if sustainability is an important aspect in their mission. The persons, representing the company, are either involved in industrial product design and/or sustainability. The largest issue for finding interesting companies is the fact that they don't know about the opportunity.

To reflect upon the approach from the perspective of each stakeholder, we reasoned about the strengths and opportunities of the teaching method, and discusses the input versus return and its threats for all parties (teachers, students and companies).

Companies' input include the context information and the problem statement they offer as case towards the students. The added value for participating companies: (i) only a limited time investment is asked from the company (two hours preparation and a half day lesson), but (ii) they achieve a minimum of twenty wild goose concepts that can be used for further internal discussion, (iii) they achieve a better understanding of the capabilities of master students in product development, which might become their future employees; and (iv) they learn new tools. Possible threats: (i) the image building of the company may be lowered due to the fact that they come outside with a specific environmental problem. However, this threat can easily be tackled towards the students, it is often a difficult internal decision for companies. (ii) as the collaboration is within the context of education, there is no guarantee for useful results.

Students' investment is funded with the credits they receive for the elective and with the knowledge they receive. In these short half day exercises, students learn both dealing with sustainable issues in companies and learn practicing ideation tools. The reality of the cases increases the value for the students enormously and triggers their interest and enthusiasm. An extra added value for master students is that they achieve in-house information of some companies, which can influence their career development interests. The largest threat for students is that due to the varying level of company-problems, the exact content of the lessons vary. Each year other tools and other contexts (and companies) are investigated, which might give the students an unfair feeling comparing the products over the different years.

For teachers: organizing this type of courses is no extra effort for teachers, as instead of writing and optimizing a theoretical schoolbook, effort is put in contacting companies, discussing the most appropriate problems and choosing the right ideation tools. Using new ecodesign tools obviously requires a good understanding of teachers how these new tools can be applied in different situations and contexts. The largest threat for the teaching staff is to ensure the availability of relevant cases. Although this seems to be interesting for companies, it is not evident to find companies that are willing to cooperate. Currently, the collaborations result from personal contact and accidental meetings. More investigation is needed to consider how this can be officialised.

In addition, we experienced an added value for other stakeholders who are sometimes involved in the different sessions. Often the new tools were developed as a result of research activities, and need further exploitation, application and verification in educational and company contexts. The context of the course is consequently used a concrete testing case.

Further discussion is needed to determine how to avoid potential concurrence with those companies who offer idea-generation-services as business strategy. Currently, the companies do not pay for the often very valuable outcome. Obviously, in contrast to those companies, these sessions are situated in an educational context and should follow the educational planning, which makes it less flexible. For the moment, these companies do not consider the university as a competitor because the amount of cases is relatively low. Further exploitation of this approach in other courses requires substantial thinking and development of a business model.

## 4 Conclusions

In this paper, we presented a new teaching approach, used in the advanced design for sustainability course, in which master students are working on different cases of real-life sustainability issues introduced by an industrial company. After founded reflection, we can conclude that the approach can considered to be innovative and very effective and enriching, due to the following aspects: (i) concrete realistic cases increase the interest of students; (ii) new tools are experienced (added value for students and companies); (iii) companies achieve wild goose ideas with a minimum time investment. (iv) The courses are structured efficiently, using a similar framework and within a limited time schedule. This allows teachers to efficiently organize the cases within their lessons.

Involvement of industry practices in an educational context is a bottleneck in many educational programs and industry (in general) is often complaining about the difference between the theoretical approach handled in university and the practical economic situation in their businesses. Nevertheless, it is experienced as a difficulty to find new companies to participate in this course.

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# From resource to process efficiency.
# Educating a new generation of georesources engineers

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**Abstract**

Even though the Circular Economy paradigm clearly puts the emphasis on recycling, it is essential to understand that we will still need for decades to explore and find resources in the earth crust. Mining is vital to feed the loop and make sure enough metals and minerals are made available to society. But, mining is also one of the most challenging industrial operations when it comes to sustainability objectives. A modern education in mineral resources engineering must build on a strong technical background but give students the opportunity to confront their knowledge with societal needs and responsibilities. The EMerald Erasmus Mundus Master program in Georesources Engineering was set up by four leading European universities with the clear objective to educate responsible professionals who will be actors of sustainable solutions. Therefore, the University of Lorraine, the Lulea Technical University, the TU Bergakademie Freiberg and the University of Liege (coordinator) designed a unique curriculum bridging the traditional gap between natural sciences and engineering, encompassing the valley too often separating the industrial operators from the stakeholders of a mining project.

The program offers a unique blend of courses from geology to mineral processing with the aim to familiarize students with the most advanced tools for improving the efficiency of processes. Field trips and industrial visits are a key component of this program as are the non-technical seminars delivered by professionals (lawyers, entrepreneurs, NGO leaders, etc.). Evaluation is often based on written reports, documentary research and short oral presentations to make sure students acquire the indispensable soft skills for efficient communication on environmental and societal issues linked to the impact of extractive activities. Internships and hands-on practices on pilot platforms or laboratory equipments are absolutely essential to reach the highest standards and meet the objectives of the master program. This is costly and can only be maintained thanks to the strong presence of the participating universities in research programs. All four universities are core partners of the EIT Raw Materials knowledge innovation community. This gives an additional leveraging effect when it comes to the education of young entrepreneurs with a strong sustainability mindset.

## 1 From georesources…

With the evolution of engineering education throughout the XX$^{th}$ century, geology has gradually disappeared from most curricula to give way to ever more specialized technological courses. As a result many engineers are disconnected from environmental issues both in terms of resource use and impact of technology on natural processes. Part of this responsibility goes to geologists themselves who tend to consider "how rocks were formed" instead of analysing "how rocks could serve society". Today, in the perspective of integrating sustainable development into engineering education, it makes no doubt that geology is key and that geo-engineers have there say just as well as bio-engineers.

The master degree in georesources engineering (EMerald, 2016) builds on a secular tradition of educating "Ingénieurs Géologues" who have an excellent understanding of the environment while at the same time having the required complementary background in processing technologies. The disposal of mining waste and the impact of extractive activities on water resources or stability are issues regularly raised during their education. Through seminars given by invited experts from industry and public sector, these engineers are also aware of the non-technical dimension of their future activity: social license to operate, environmental and mining laws, due diligence studies for mining operations, etc.

## 2 … to engineering

The extractive industry is not perceived as being at the forefront of innovation and there is often reluctancy to change due to the very high operational costs. This situation is clearly undefendable and strong winds are blowing to boost innovation and process efficiency in the mining sector. In a modern georesources engineering degree it is essential to face young students with the challenges of innovation and creativity. Promoting biodegradable reactives in flotation or leaching; Developing the "invisible mine" thanks to advanced automation and robotics; Extracting "more out of ore" and considering mining waste as potential resources are only but a few of those innovation challenges.

Being innovative is stimulated through team work and linking with the other actors of the materials value chain (e.g. material sciences). Georesources engineers are not just the starting point of a production process, they are also key players in trying to "close the loop" (Pirard and Greberg, 2016). The engineering skills to extract valuable resources out of underground mines or urban mines are very much the same!

## 3 Hands on training

Engineering education is not just about numerical simulation and optimization… it is about understanding the complexity and the real size of challenges. Therefore, field trips to past and present mining areas to understand the best available practices and some errors of the past are essential in the curriculum. Students are also challenged to recover valuable materials out of complex ores by testing their own ideas on pilot-scale technology platforms.

## 4 Soft skills and entrepreneurship

During the last semester, students are immersed in a three week intensive business school to develop their entrepreneurial mindset before joining an industrial partner for internship and master thesis. They will later have to share this unique experience with a broader public during the graduation ceremony which includes a five minutes pitching exercise. Sustainable development requires from young engineers to be excellent in communicating their research and making more perceptible their efforts to the benefit of society and the natural environment.

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# Educating Engineers to a Broader View of Sustainable Development

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**Abstract**

The world is becoming an increasingly complex environment in which to seek transformation by means of engineering. This complexity is reflected not only in the need for engineers to collaborate with other professionals from a wide background of disciplines but also in the complexity of the problems in social, technical, ecological, economic, ethical and political terms. The idea of sustainable development is itself part of a more complex environment within which future engineers will need to work. Universities worldwide attract large numbers of international staff and students: this adds an additional dimension to the broader view, with intercultural, as well as interdisciplinary, working. Increasingly, engineering curricula seek to embrace ethical and social issues. In Manchester, an interdisciplinary course unit in sustainable development for engineers and scientists has spawned a number of course units relating not just to sustainable development but also embedding ideas, for example, of entrepreneurship, humanitarian aid and emergency response. The common theme has been that of tackling complex real-world issues. In some instances these units have been run exclusively for engineers, even engineers from a single branch of engineering, and in other cases the units are run with students from a range of backgrounds. This paper describes the approach being taken in selected course units in Manchester and their relevance to the wider context, particularly in the context of ideas about working across disciplines as well as the relationship between sustainable development and other global issues. This includes comparison between units run in an essentially mono-disciplinary context with others where the intention is that they should be inter-disciplinary.

## 1 Introduction

### *1.1*

The world is an increasingly complex environment in which to seek transformation through the means of engineering. Universities have often responded to this complexity by simplifying problems so that students can tackle easier questions, lacking the complexity of social, technical, ecological, economic, ethical and political environments. Rietje van Dam, at that time Vice-Rector Magnificus of the University of Leiden, suggested at a side meeting of EESD 2008 in Graz that a major issue for universities was that they tended to reduce the complexity of issues in order to make them simpler for students to tackle, particularly in the sciences and engineering. On leaving university, graduates face complex, ‘wicked’ problems, including those global societal issues that stem from the need for sustainable development as well as from other natural and political issues. The University of Manchester has a stated commitment to global citizenship and attracts large numbers of international staff and students: this adds an additional dimension to the broader view, with intercultural, as well as interdisciplinary, working. Global inequality is also one of the university's five "research beacons" and this feeds through into the curriculum in terms of ethical and social issues such as inequality. In Manchester, over recent years, a number of course units have been developed relating not just to sustainable development but which embed ideas, for example, of entrepreneurship, humanitarian aid and emergency response. The common theme has been that of using problem-based learning, though in a number of variants, including some with study undertaken online. In some instances these units have been run exclusively for engineers, even engineers from a single branch of engineering, and in other cases the units are run with students from a range of backgrounds.

### *1.2 Questions of definition*

The definition of Education for Sustainable Development is one agreed at the beginning of the series of projects and states that it "aims to enable the professional engineer to participate, with a leading contribution, in decisions about the way we do things individually and collectively, both locally and globally, to meet the needs and aspirations of the present generation without compromising the ability of future generations to meet their own needs and aspirations." (Tomkinson B: 2009). The approach used throughout is also predicated on the tenets of the Brundtland (1987) Report, which can be summarised in a list of a number of significant challenges that face the future of the world:

- Economic burden of large national debts;
- Reduction of biodiversity;
- Pollution of air, soil and water, with detrimental influences on the environment;
- Growth of world population, accompanied by increasing poverty in the developing world;
- Competition for limited water supplies, resulting in threats of armed conflict;
- The threats and consequences of climate change.

*These developments stimulate extremism, terrorism and migration that affect social stability.*
Many of those challenges have assumed a greater urgency in the intervening years.

The idea of 'wicked' problems stems largely from the work of Horst Rittel and Melvin Webber (1973). These are radically different to the 'tame' problems that tend to be given to students, particularly in science and engineering. In the field of global societal responsibility there is usually an additional dimension, in that different proposals may appeal to different stakeholders and any solution may advantage some of these whilst disadvantaging other groups in society. Finding an appropriate solution may then become a social and political issue rather than a technical one.

Elsewhere (Tomkinson B et al: 2008), the authors have tried to distinguish the meanings in using ideas of *trans-disciplinarity, inter-disciplinarity* and *multi-disciplinarity* (but not the more opaque pluri-disciplinarity or meta-disciplinarity). Ideas about the necessity of an inter-disciplinary approach in resolving complex issues of sustainability were surfacing in other quarters at much the same time as Charles Engel (Engel C et al: 2004) was advocating an interdisciplinary approach to global societal problems. Gertrude Hadorn and others (2006) pointed to ideas about the reformation of higher education along trans-disciplinary lines, in order to co-ordinate activities towards a common good, as long ago as 1972. They go on to suggest that sustainability research is predicated on a common understanding, in a fashion that we would now regard as multi-disciplinary in that it draws only what it need from contributing disciplines. This implies that approaches to sustainability draw solely on knowledge, not on skills or attitudes. Martin Davies and Marcia Devlin (2007) point to areas where disciplines combine their expertise to address an area of global concern, such as pandemics, global warming and climate change. Ralf Brand and Andrew Karvonen (2007) suggest that sustainability poses challenges to the discourse of technical experts and that many existing models do not fit with traditional disciplinary boundaries. In this context, the education of engineers and scientists in sustainability literacy has to be looked at outside the disciplinary framework. Nathalie Lourdel and colleagues (2005) emphasize the need for an holistic approach to education for sustainable development for engineers: “Theoretical classes are not sufficient. It seems important to help them to transpose theoretical knowledge into professional and day-to-day activities.”

In the Manchester context, teaching necessarily spans national cultures – in science and engineering many programmes have a majority of students from outwith the UK and almost half of the teaching staff were born overseas. By analogy with the above interpretations of disciplinarity, *Multi-cultural* activities would be those where students from different cultures learn or work in the same space, with each culture operating within its own cultural framework; *Inter-cultural* activities would be those where students from different cultures learn and work together, sharing views and discussing issues across cultural boundaries; *Trans-cultural* activities arise when students work or learn together on issues that span cultural boundaries or where the students learn with, and from, teachers from another culture.

## 2 A Suite of Courses

The original exercise, supported by the UK Royal Academy of Engineering has been widely reported (Tomkinson B: 2009). This sought to use the approach of problem-based learning (PBL) to tackle complex, real-world problems with groups of undergraduate students drawn from a range of science and engineering disciplines. That model still applies today, though with some modifications. Figure 1 shows, graphically, a representation of the growth of the approach to other levels of study, other engineering disciplines groups of students and other universities, in the UK and elsewhere. The first stage of development was to increase the numbers participating on the Interdisciplinary Sustainable Development module from the initial pilot unit numbers: currently about 200 students participate on this unit, but participation has also been extended beyond science and engineering programmes. The proportion of students from outwith science and engineering has doubled in each of the last two years, from about 4% three years ago to some 15% in this current year. Following concerns about the balance of student numbers, mandatory participation by Electrical Engineering and Electronics students was changed to allow for a mono-disciplinary unit run just in that School. The group responsible for many of these units was transferred to the Enterprise Centre in the Manchester Business School: this led to the development of additional units within that School, both at undergraduate and postgraduate level.

At the same time, members of the team who had remained in the Faculty of Engineering and Physical Sciences were invited to run interdisciplinary Summer Schools at Kymenlaakso University in Finland (Peltola: 2013). Others were invited to join an action research project, funded by the National Teaching Fellowship Scheme and led by the University of Keele, looking at hybrid (ie a mixture of online and face-to-face) approaches (Bessant et al: 2013). Within Manchester a further innovation, using teaching development funds, was to create an optional Masters level unit in Managing Humanitarian Aid Projects. This was within the Management of Projects MSc but was also attended by Humanities students from the International Development Policy and Management programme. All of the units have started off with a PBL approach, though this has later been modified in some cases. The scenarios used have overlapped to a certain extent, with broader ethical, political and social issues included in many of the sustainable development scenarios and issues of long-term sustainability being a key feature of units in Humanitarian Aid and, subsequently, Emergency Projects. Some have featured in more than one unit – for example an issue about using microelectronics to monitor fruit and vegetables being transported across the globe featured in both interdisciplinary sustainable development and the course unit solely for Electrical and Electronic engineering students; an issue about post-disaster rebuilding featured in both the Humanitarian Aid and interdisciplinary sustainable development modules. Equally, the initial idea was that all groups should have a facilitator – usually a Post-Doctoral researcher or PhD student – on a one-to-one basis. With pressures on resource this has become diluted so that one facilitator might oversee several groups or, in some cases, the lecturer is the sole facilitator for all groups.

## 3 Analysis

Many of the units developed in this suite have been subject to a considerable amount of monitoring and evaluation, much of which has already been published (Bessant et al: 2013; Hill et al: 2013; Hill et al: 2016; Dobson & Tomkinson: 2016). This has meant that there is data, some of it qualitative, that has been used to look further into the issues, for example of porous boundaries for sustainable development. Initially, questionnaire data was collected but the norm has been to collect data using the nominal group technique (Delbecq, Gustafson & Van der Ven: 1975) both with students and with facilitators. Questionnaires have continued to be applied, for more specific investigations. These have included studies concerning learning style, culture, employability and assessment.

The initial feedback from the mono-disciplinary unit for undergraduate Electrical and Electronic Engineers was relatively unfavourable. This unit had been set up partly in response to feedback from students in the previous year who had attended the interdisciplinary unit, where it was felt that the Electrical and Electronic Engineering students overwhelmed the groups. However, many of the adverse comments concerned relevance, despite most of the scenarios having an electrical or electronic bent. Further discussion of this suggested that, for some, the concern was that issues of sustainable development are not seen as relevant to electrical and electronic engineering whereas for others the groupwork approach was being questioned. Frances Hill and others (2016) looked at learning styles amongst students on another of the suite of courses – an option that could be regarded as interdisciplinary. The intention was to look for differences in learning style between students from different cultural backgrounds but the findings suggested that here was more difference between those with different disciplinary backgrounds than those with different national cultures. The key point here was that students with a Social Sciences background had a greater orientation towards social learning and those with Science or Engineering backgrounds a greater orientation towards solitary learning. From the nominal group data there was some inclination for students to report working with other disciplines as a positive feature, and the lack of access to some disciplinary expertise as a negative one. This was more frequently reported by the facilitators.

Issues of employability have been addressed in two studies in this sequence. A project led by the University of Keele and funded by the UK National Teaching Fellowships Scheme (Bessant et al: 2013), looked at developing hybrid approaches to embedding sustainable development including an element of online learning. As part of this study, students at Manchester were the subjects of focus groups and nominal groups as well as of questionnaires (Bessant: 2012). In looking at students' perceptions of how their skills had developed, Manchester students reported that their professional skills had improved slightly or greatly as a result of the course unit, with communications and listening skills showing an improvement reported by 80% of students up to 100% of students reporting an improvement in team-working and reflective skills. In reply to a question about whether the unit had improved their chances of getting a job, 93% of Manchester students suggested that it had enhanced their employability skills. In a subsequent study, Frances Hill and colleagues (2013) sought the views of graduates of such a module two years after leaving. The response was relatively small, so the results have to be treated with some caution, but respondents generally responded that the unit had helped develop their skills for employment. Hill developed a scoring system that multiplied the perceived development by factors relating, first, to the perceived importance of the skill for the role of the respondent and, second, the perceived importance to the employer as elucidated in the job description. Skills which showed the highest added value for importance in their role were:

1. Working in a team on a group task
2. Listening to others opinions and respecting differences during group work
3. Negotiation

4. Identifying and solving problems when presented with a task, and
5. Effective discussion

Skills which showed the highest added value for importance to their employer were:

1. Working in a team on a group task
2. Identifying and solving problems when presented with a task, and
3. Effective discussion.

Note that these are all *skills* rather than *knowledge* and develop from studying through PBL: they would be far more difficult to develop using conventional didactic approaches. Omonigho Otancha (2015) conducted further surveys that suggested that 96% of students on one of these units agreed both that "the course provided opportunities to enhance skills that will be useful to me in the future" and that "This course enabled me to connect academic concepts with real world examples"

## 4 Discussion

Arjen Wals (2009) argues that Education for Sustainable Development "calls for new kinds of learning that are not so much of a transmissive nature (ie learning as reproduction) but rather of a transformative nature (ie learning as change). The latter requires permeability between disciplines, schools and the wider community and between cultures, along with the capacity to integrate, connect, confront and reconcile multiple ways of looking at the world." His report suggests fourteen learning outcomes for education for sustainable development:

- Critical reflective thinking
- Understanding complexity/systemic thinking
- Futures thinking
- Planning and managing change
- Understanding inter-relationships across disciplines
- Applying learning in a variety of life-wide contexts
- Decision-making, including in uncertain situations
- Dealing with crises and risks
- Acting with responsibility locally and globally
- Ability to identify and clarify values
- Acting with respect for others
- Identifying stakeholders and their interests
- Participating in democratic decision-making
- Negotiating and consensus building.

These are not easy to teach using conventional didactic approaches.

Jack Mezirow (1997; 2003) describes transformative learning as '...[transforming] problematic frames of reference' which should '… make them more inclusive, discriminating, open, reflective and emotionally able to change'. He suggests that education increasingly discourages this approach to learning rather than encouraging it. Looking at Wals' list it is apparent that many of the attributes sought are of skill rather than knowledge and this implies that professionals have to act as autonomous thinkers in a collaborative context rather than acting uncritically on received wisdom. This is reinforced by a UK Royal Academy of Engineering guide (Dodds & Venables: 2005); "Sustainable Development redefines the context within which the skills must be deployed. … Engineering input to sustainable development solutions must be provided in partnership with many other interests. For sustainable development to be achieved, professional practice in engineering needs urgently to have a much wider compass than the development of elegant solutions to narrowly specified technical problems." The guide also emphasises that "the leadership and influencing role of engineers in achieving sustainability should not be under-estimated. Increasingly this will be as part of multi-disciplinary teams that include non-engineers, and through work that crosses national boundaries".

Progress is never without impediment and this is true in courses dedicated to global societal responsibility and to courses using dilemma-based learning. The main block to progress has been the tightening of resources such that it has not been possible to employ many (if any) facilitators to help with groupwork. The quest for greater efficiency in assessment has also been problematic for an approach to learning that hinges on formative feedback on a series of assignments. This is not unique to Manchester and other universities using related approaches have reported course units being suspended or terminated for reasons of 'efficiency'. This illustrates a gap in understanding between those who wish to foster *effective* rather than *efficient*, or merely *economic* approaches to learning.

## 5 Conclusions

The broader view of sustainability enhances engineering students' career prospects and helps them to tackle wicked global problems. These units relating to sustainable development have demonstrated the capacity of the approach to embrace wider concepts and a broader audience. However, the process has not been without difficulty. The move from optional units to mandatory ones, and inter-disciplinary units to mono-disciplinary ones, has demonstrated both opportunity and challenge, but it is difficult to say which has formed the bigger barrier. There is some resistance from students to the idea that they need to familiarise themselves with social, economic, political and environmental aspects as well as technical ones. Where the need for collaborative working is recognised it is often compartmentalised so that it can be isolated from the engineering aspects. Part of the reason for this may lie with the perspectives of colleagues who were not taught this way and who may not have practised engineering in industry for a very long time, if at all. The idea that sustainable development (or whatever phrase might embrace it) is more than the design – manufacture – maintain – reuse cycle can help students to embrace the more complex challenges that they face on gaining employment and equip them with valuable skills that will give them the edge in gaining that employment. Part of the solution may lie with a greater emphasis on the development of colleagues to help them to understand, and contribute to, the broader picture: to understand the long-term global consequences of short-term economies.

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# Patterns of Engagement: Using a board game as a tool to address sustainability in engineering educations

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**Abstract**

The Global Dimension in Engineering Education (GDEE) refers to all non-technical topics that will impact the engineering profession at a global level over the next couple of decades. As teachers at a Media Technology engineering programme at the KTH Royal Institute of Technology, School of Computer Science and Communication, we have definitely felt that substantial amounts of ingenuity is required to make students interested in such topics, since many of the students regard them as non-central or of little interest when compared to their (non-GDEE) "core" interests, skills and aspirations.

We here describe how we have worked to overcome students' (potential) aversion to one particular GDEE topic, sustainability, by incorporating a board game, Gasuco, into the introductory module of a course about "Media Technology and Sustainability". We describe and analyse our use of the game in terms of "pedagogical patterns for learning" (Laudrillard, 2012).

## 1 Introduction

The Global Dimension in Engineering Education (GDEE[1]) refers to all non-technical topics that will impact the engineering profession at a global level over the next couple of decades. These topics include sustainability as well as globalisation, ethics, inequality, poverty, climate change etc. While the topics addressed by GDEE might draw some students to engineering educations, we suspect that the majority of students currently studying engineering educations do this for reasons that are unrelated to "the global dimension" and that it furthermore can be hard to motivate such students as to the importance of GDEE topics. As teachers, we have certainly felt that substantial amounts of ingenuity is required to make our students interested in such topics (Pargman & Eriksson, 2013, Eriksson & Pargman, 2014), despite the fact that the importance of several of these topics is already specified and embodied in the Swedish Higher Education Ordinance.

As a way of meeting these challenges, we have introduced a board game, Gasuco, into the first part of a compulsory course about "Sustainability and Media Technology" that is given to our fourth-year Media Technology engineering students. The course has been taught four times (2012-2015) and we have utilized the game in the course during the last three cycles. We have collected a wealth of materials about students' attitudes and opinions about the game and the course as well as their attitudes to, and self-reported knowledge about sustainability through pre-course questionnaires, post-gaming questionnaires and course evaluations. We have furthermore conducted interviews with

[1] See further http://gdee.eu

students and have observed students playing the game during dozens of gaming sessions. This paper will however not primarily focus on the *effects* of using the game, but rather on the *justification* and the outcome of using the game in terms of its' pedagogical merits. What in the game itself, and what in the use of the game makes it successful for our purposes?

We answer these questions below by way of outlining the pedagogical theories and the thinking behind our use of the game Gasuco in our course. We discuss the use of the game through the lens of design patterns and analyse how we have used it as a tool for for teaching a GDEE topic in terms of developing a "pedagogical pattern for learning" (Laurillard, 2012). We argue that a game such as Gasuco represents an activity that is appealing for a variety of reasons, and not the least because it constitutes a very low threshold to introducing GDEE topics to engineering students.

## 2 Theory

Design patterns have been described as "*semi-structured descriptions of an expert's method for solving a recurrent problem, which includes a description of the problem itself and the context in which the method is applicable, but does not include directives which bind the solution to unique circumstances. Design patterns have the explicit aim of externalizing knowledge to allow accumulation and generalization of solutions and to allow all members of a community or design group to participate in discussions relating to the design*." Design patterns have been applied in many different disciplines such as software engineering, hypermedia, and interaction design (Mor & Winters, 2007).

In pedagogy and Technology Enhanced Learning ,TEL), the related concept "pedagogical patterns" has been suggested as a relevant way to describe the outcome of pedagogical research when seen as a design science (Laurillard, 2012). Laurillard suggests that a pedagogical pattern can be described as a sequence of teaching-learning activities. She has also linked pedagogical patterns to learning design principles through a Conversational Framework (ibid., p.103) that contains five different cycles:

- **Teacher-Communication-Cycle (TCC).** The teacher gives students access to the teacher's concept (books, lectures, videos and so on) (TCC1), the students are motivated to generate questions or articulate their perceptions of these concepts (TCC2), and the teacher provides feedback on these questions or articulations (TCC3).
- **Teacher-Practice-Cycle (TPC).** The teacher provides a practice environment where the student can practice (TPC1) and get feedback from the teacher (TPC2).
- **Teacher-Modeling-Cycle (TMC)**. The teacher provides a modeling environment where the students can practice (TMC1), but where the feedback is given by the environment itself (TMC2) rather than by the teacher.
- **Peer-Communication-Cycle (PCC).** The student modulates his/her concepts by communicating with, and getting access to peers' concepts (PCC1), generates questions or articulates perceptions of peers' concepts (PCC2), and peers provide feedback on these questions or articulations (PCC3).
- **Peer-Modeling-Cycle (PMC).** The student gets access to the output of peers' practice, such as a chapter in a thesis, or a computer program (PMC1), which enables the learner to modulate their own practice by using their peers's output as a model (PMC2).

In the board game we focus on, there are both Teacher-Communication-Cycles (TCC) and Peer-Communication-Cycles (PCC), but we are for the purpose of the paper primarily interested in the latter.

Our emphasis on the importance of Peer-Communication-Cycles (PCC) is based on a social constructivist view of learning, resting on Vygotsky observation that "*all the higher [psychological] functions originate as actual relations between human individuals*" (Vygotsky, 1978). However, not all kinds of peer discussions lead to actual learning. Results of several research studies conclude that peer discussions should have certain characteristics in order to support actual learning (Laurillard, 2012, p. 143). According to Laurillard, students in peer discussion activities should:

- "*Take a particular position with respect to a concept or conjecture*
- *Provide evidence and explanations for their arguments or position*
- *Consider, respond to, or challenge counter-arguments, share and critique each other's ideas*
- *Reflect on their own perspectives in relation to those of others*
- *Work towards an agreed output, negotiating meaning, or collaborating on a decision*."

We believe that Gasuco satisfy *all* of these characteristics.

## 3 Playing Gasuco

The course in which we use Gasuco is comprised of two relatively independent modules. The first module treats sustainability as a topic in its own right, while the second, larger module in various ways connects sustainability to the topics of computing and information technology. The game is a major component of the first module and it constitutes an important element of how we introduce the topic of sustainability to our students.

While Gasuco is used in several different educational programmes at KTH and elsewhere (Dahlin et. al., 2013, Dahlin et. al., 2015), we believe that ours is the only programme with an ICT profile that uses it, and, we have customized the game so as to better fit this particular group of student (Eriksson and Pargman, 2014). The game has been customized primarily by replacing approximately 25% of the Discussion cards (see below) with discussion topics that specifically relate to ICT and Sustainability. While the game has relatively simple rules, we will not exhaustively describe how it is played, but will here rather concentrate on game element that are of relevance to Laurillard's Conversational Framework. Figure 3 (at the very end of the paper, below the references) does however provide a snapshot of a gaming session.

The nominal goal when playing Gasuco is for students to try to gain *EES cards* (representing Economical, Ecological and Social perspectives on sustainable development) and *Discussion cards* to fill their "Portfolio". EES cards are won by successfully answering *Mini fact* questions (where students' answers are either right or wrong), while Discussion cards hinge on the student successfully "leading a discussion" on the topic specified by the card for the duration of three minutes. *Opportunity cards*, finally, affect the EES cards in different ways and they come in two different varieties: *Association cards* that demand that the student connect three terms and talks coherently about them for one minute and *Concept cards* that allow a student to challenge another student to explain a concept by explicating and talking coherently about it for one minute. See Figure 1 and Figure 2 below for examples of the various cards. While all cards can lead to communication and discussions among students (peers), it is worth explaining how the Discussion cards in particular are used in the game. The instructions (from the short leaflet with the rules for the game) are as follows:

"*The Discussion cards contain questions that players should motivate, discuss and reflect upon. The player who draws a Discussion card ... leads a discussion as follows: the player reads it out loud and* *then motivates an opinion. The other players then actively contribute and either agree, dispute or emphasize another perspective. It the player manages to lead and involve all players in the discussion (as determined by a majority decision by the other players) the card is considered won*"

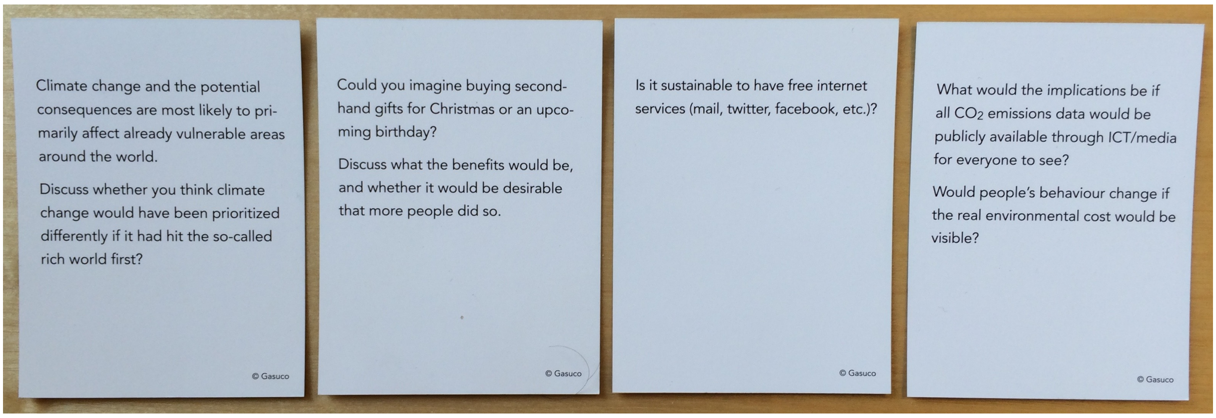


Figure 1: Four of Discussion cards from the Gasuco board game. The two cards on the left treat issues of sustainability in general while the two cards on the right treat issues about sustainability and ICT.

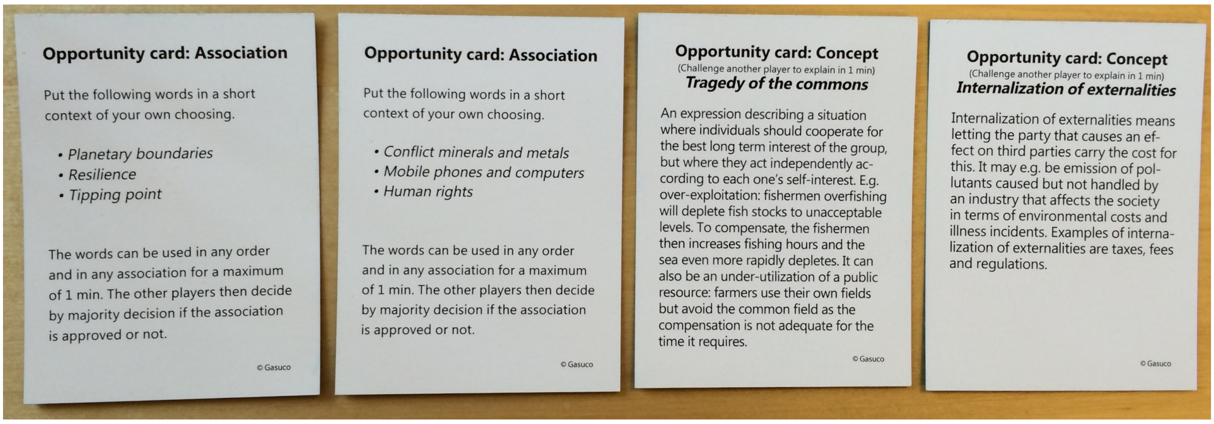


Figure 2: Four Opportunity cards from the Gasuco board game. The two cards on the left are Association cards and the two cards on the right are Opportunity cards.

The specified length of time that students should spend on each Discussion card (three minutes) makes this game element the biggest source of peer communication during a gaming session. Discussion card topics are usually very open-ended (see Figure 1) and they typically have no clear right or wrong answer. This makes them attractive in a learning setting as there is plenty of space for various and differing opinions, as well as fewer opportunities to reach consensus. This can at times lead to very lively discussions. Lastly, it is a matter of judgement (and negotiation) to decide if a student has succeeded in his/her role as discussion leader.

We have here very briefly described the game in terms of relevant gaming mechanics and gaming elements and will below analyse the use of the game in terms of Luarillard's Conversational Framework and its five cycles of teaching-learning activities. These cycles can in turn be connected to the main objectives of using the game in the course; 1) spark and increase students' interest in and motivation *for* sustainability, 2) increase students knowledge *about* sustainability and 3) support social process and opportunities for (primarily recently arrived foreign) students to extend their social networks. The latter goal lies outside the scope of Laurillad's Conversational Framework and will not be further discussed in this paper.

## 4 Results and analysis

The overarching purpose of using the game is to engage students in the topic of sustainability, and the different game mechanics can be conceptualized in terms of different cycles in Laurillard's Conversational Framework. However, the game is not a stand-alone learning activity, but is coupled to preceding and succeeding lectures in the course module. This "package" (intertwined lectures and gaming sessions) mainly invokes Teacher-Communication-Cycles (TCC) and Peer-Communication-Cycles (PCC). A formalized way to analyse and describe these learning activities is to use a pedagogical pattern. We have used the "Teaching Method Template" (Derntl et. al. 2009) to describe that pedagogical pattern (see Table 1 below).

A series of lectures prioritises one single teaching-learning activity, TCC1, even if there is also (oftentimes very limited) time for student questions (TCC2) and for the teacher to answer those questions (TCC3). Such a structure decreases the opportunities for students' deep learning. By playing Gasuco, students have access to the whole spectrum of the Teacher-Communication-Cycle (TCC1, 2, 3) - even if it in fact are other students who might have to step in and try to take on the role of the teacher when explicating the teacher's concepts (TCC1). Students furthermore have access to the whole spectrum of the Peer-Communication-Cycle (PCC1, 2, 3) when playing the game. It is in particular the Discussion cards that engage students in Peer-Communication-Cycles and it is subsequently these cards in particular that we have chosen to customize so as to make the game more engaging for this particular group of students. We conclude that the game significantly increases the opportunities for deep learning and it is also more engaging than only listening to a series of lectures. What then do the students think about the game?

After the latest cycle of the course (2015), 42 out of 79 students answered the post-gaming questionnaire and 38 of them answered the free-text question "What is your opinion of the Gasuco gaming sessions?". While the vast majority of students were generally positive, there were also a few dissenting opinions.

Positive aspects were related to several areas, such as being fun and engaging ("*it was fun and engaging – memorable*"), peer learning ("*it helped me a lot to learn from my fellow peers, who were very willing to explain and share their views*"), getting new perspectives ("*it is important to discuss with other people to be able to understand the subject from another view*"), feeling more at ease with the course ("*it helps making students feel more at ease with the course: we are more confident that we've assimilated what we learnt during the lectures*"), learning terminology ("*it helped me get to know more important terms*"), learning in small groups ("*speaking in [a] little group with just four people is a good idea, because sometimes it is difficult to take the floor and speak in front of a crowded classroom*"), as a discussion starter ("*an easy way to start interesting discussions*") and to get to know other students ("*it was great to get to know the others in the group*").

There were also some negative comment, for example about game mechanics ("*why is the discussion card worth 2 points? They're so much easier to get than the mini fact or opportunity card*"), about game design ("*I didn't feel the need for the individual gaming board, you can just as well save the cards in a pile in front of you and count each card as a point*"), of not having sufficient knowledge ("*it was however a bit frustrating playing the game when I felt like I didn't know enough*"), of questions being too difficult ("*sometimes the questions were rather hard to understand or discuss therefore the level of learning from the conversation was rather low*") and of difficulties with different levels of knowledge among students ("*good, but there is a huge knowledge gap in the class, some people can barely discuss the topics.*").

Table 1: A Pedagogical Pattern for learning sustainability through a game.
Topic-specific parts are in brackets and in italics.

| **Title** | **Boardgame for learning [*sustainability*]** | | |
|---|---|---|---|
| Origins | KTH Royal Institute of Technology, Media Technology and Interaction Design | | |
| Summary | In three cycles, students are, during lectures, introduced to a number of [*sustainability*] concepts. They later learn facts as well as discuss and motivate standpoints while playing a game in small (four-person) groups. | | |
| Learning outcome | To be able to explain and discuss important topics related to [*sustainability*]; a significant non-learning outcome is to increase engagement and motivate the students for the rest of the course. | | |
| Rationale | Social constructivism; peer learning | | |
| Duration | 3 x (2h + 2h) | | |
| Learners | [*Fourth year Media Technology engineering students taking a course in Media Technology and Sustainability.*] | | |
| Setting | Classroom | | |
| Resources and tools | [*The Gasuco game.*] | | |
| **Learning cycles** | **Sequence of teaching-learning activities (repeated three times in two weeks)** | **Group size** | **Time (mins)** |
| TCC1 | A lecture about [*sustainability*]. | 70 | 2 x 45 |
| N/A | Short introduction from the teacher about the game [*Gasuco*] and today's gaming session. | 70 | 5 |
| See below | Students are divided into small groups, each group playing the game for the remainder of time, in turns engaging in the activities described below. | 3-4 | 100 |
| TCC1,2,3 | MiniFact cards - Another player draws and reads a question from a Mini fact card aloud. The player tries to answers the question. The correct answer is printed on the card. | 3-4 | 1 |
| PCC1,2,3 | Discussion card - The player reads the card aloud and then states and motivates his/opinion opinion. The player then leads a discussion where the other players should actively contribute by agreeing, challenging or emphasizing other perspectives. The other player decides if the player succeeded in leading the discussion and in involving all the other players. | 3-4 | 3 |
| TCC1,2,3 | Association card – The player should associate the different terms on the card in a context. The other players determine if the player succeeded. | 3-4 | 1 |
| TCC1,2,3 | Concept card – The player challenges another player to explain or exemplify a concept written on the card in one minute. The answer is printed on the card. | 3-4 | 1 |
| Designer's reflection | Students often flaunt suggested time limits and discuss concepts and topics for as long as they feel like it, using the game more as a scaffold for discussons than as a goal-oriented activity. Various (national and other) student backgrounds oftentimes adds to the discussions. | | |

## 5 Discussion

The discussion cards and corresponding game mechanincs facilitete each of Laurillad's (2012) five characteristics for making peer discussions support actual learning (see the theory section above). Answers from the student questionnaire back our conclusion that the discussions indeed *did* promote learning in the intended, hoped-for way. There is also clear evidence that a majority of the students considered playing the game a fun and engaging activity, thereby supporting our goal of engaging students in learning a GDEE topic that many could consider being peripheral to their education.

An important outcome of this paper is the pedagogical design pattern for using a board game for learning about sustainability in an engineering education (Table 1). Neither the pattern nor the game itself is by necessity tied to to the specific topic of sustainability, as seen in Table 1 where all topic-specific parts are in brackets and italics. It should therefore not be too hard to transfer the same concept (i.e. the same pedagogical pattern) to other GDEE topics or to other engineering programmes.

The gaming sessions are easy to administer and the only hard requirements are a suitable locale and a sufficient number of games (one game for every four students). The main threshold would be to either find an existing game that is suitable (and perhaps customizable), or to design and produce a new game. Latching on to an existing game is convenient, but might require existing lectures to be adapted to the game, or for the game to be adapted to the lectures/course in order to, for example, make sure that the questions are not too easy or too difficult (see the negative comment above). Developing a new game makes it possible to customize it to the target learners and courses, but of course requires significant resources in terms of time, money, game-development skills and access to production facilities etc. As was described in the paper, we have customized the game so that 75% of the Discussion cards treat questions that are related to sustainability in general and 25% treat ICT and sustainability in particular. Based on our experiences, we are now considering increasing the proportion of ICT-related Discussion cards, perhaps aiming for a 50/50 balance between these two categories of questions.

Our experiences of using the game in our course are very positive, as are the experiences of (the majority of) the students. While it is possible to play the game competitively (there is a scoring systems), it is much more common for students to use the game as a scaffold for discussions, often flaunting the guidelines for time use, for example discussing a topic that catches their interest for five minutes instead of the allotted one or three minutes for Opportunity cards and Discussion Cards respectively. In the spirit of *not* playing competitively, we have also noticed that it is unusual for students to flunk other students in their role as discussion leaders. It seems to be more common for students to admit that they didn't know very much about a topic and that they themselves feel they are not "worth" winning the card in question. While students thus can blatantly disregard the formal rules of the game, no one is happier about it than us teachers. It is furthermore not unheard of for students to stay and to continue to play the game until the allotted time is up, rather than when someone has won the game. We find that it is especially beneficial to have these gaming sessions at the very start of the course as they tend to "draw in" students and make them interested in the topic of sustainability and the contents of the remainder of the course.

## Acknowledgements

We would like to extend our thanks to the Gasuco game designer, Patrik Larsson, for his passion about teaching about sustainability and energy issues to university students, and for his responsiveness to our requests for customizing the game. We also want to thank the Swedish Energy Agency for funding.

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Figure 3: A snapshot from a Gasuco gaming session.

# Sustainability degrees or Sustainability integrated in traditional disciplines: a strong argument for a golden mean and the rough journey to get there.

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**Abstract**

Sustainable Development has quickly become the challenge of today; however, for many educational organizations the encompassing framework of Sustainable Development, providing the student with basic knowledge and skills related to various specific articulations of Sustainable Development(van Lente and van Til 2008; Mulder et al. 2011) is too much. Training T-shaped professionals (Kelley and Littman 2005) has been suggested in order to train professionals that both acquired sufficient general knowledge to enable the graduate to develop integrated solutions for 'sustainability problems' and to have acquired sufficient specific expertise to contribute sufficiently to the expertise base of a project teams.

This paper describes and evaluates the journey by which The Hague University of Applied Science (THUAS) developed a program to train T-shaped Climate Change & Management specialists. The program was created 9 years ago and changed several times in an ongoing iterative process that involved local stakeholders. The environment of the program keeps changing, creating new challenges, new ideas as well as less successful ideas.

The paper analyses the process that shaped the program, and evaluates the results in terms of student-, lecturer- and employer satisfaction. It concludes that the T-shaped professional targeting a specific articulation of sustainability, is a productive approach to train experts to contribute to Sustainable Development.

It concludes that three elements are crucial to create a sustainability focused BSc. program. Firstly, the staff's competences: staff members have sustainable development in their genes, as well as the competence to cooperate in interdisciplinary groups. Secondly, employer's needs for professionals in sustainable development are crucial. Thirdly, the study program should be structured clearly and flexibly, which means that new (sustainable) developments can be implemented quickly and smoothly.

**Introduction: The success story of a BSc program on Climate & Management**

The BSc program Climate & Management at The Hague University of Applied Sciences (THUAS) has been awarded the national label 'top study program' for three years in a row, rated a 4.2 out of 5 in 2015 (Keuzegids, 2015). The program is about sustainable development in the built environment, focusing on climate adaptation and mitigation. The program was created 9 years ago and was adapted several times in an ongoing iterative process. The main drivers for these iterations were transformations taking place in the built environment and the commitment to train students for excellence.

Local stakeholders are closely involved in the program to feed the program with relevant changes in the built environment sector. This paper analyses the process that shaped the program, and evaluates the results in terms of student-, lecturer- and employer satisfaction. The paper will first describe how the curriculum was developed and how support was acquired. In this historic account, the paper will focus on how the philosophy of the program got its current form. Afterwards the paper will analyze the results of the program in terms of satisfaction of students, staff and employers, external evaluations and self-reviews. Finally, we identify challenges for further improvement.

The program has been rather successful in various respects. Factors that have been crucial for this success are identified and the applicability of these factors is further discussed.

**Creating a program on Climate and Management**

The three founders of the program Climate & Management have been interviewed to describe the creation of the program, its context and the early challenges to overcome.

In 2005, a study of the Netherlands Bureau for Economic Policy Analysis (Noailly et al, 2005) concluded that there could be a future scarcity of science and engineering students in the Netherlands. Since then, the Netherlands developed several programs to attract more technology students. THUAS tried to do so by broadening the focus of the engineering programs. It aimed to attract a different type of engineering students. In line with this view, a few years earlier the program Commercial Engineer had been created at THUAS. Furthermore, it was thought that another type of students could be attracted as well: those who are interested in sustainable development, and more general in society, but who fear that an SD qualification alone does not provide sufficient opportunity at the labor market.

The first global climate treaty, the Kyoto Protocol, came in force in 2005. In 2007, Al Gore and the Intergovernmental Panel on Climate Change (IPCC) won the Nobel Peace Prize. Climate change, and therefore mitigation and adaptation, was now on the global political agenda.

> *Climate change, whether mitigation or adaptation, has become a media hype. In general, the focus is on one specific frame in which the problem has been discussed. Herewith, the problem is very recognizable, but causes difficulties when crossing borders. The problem perception is fragmented, causing directors and policy makers to choose too quickly for sectoral, technical solutions.*
>
> *Instead of climate policy in terms of uncertainties and defensive, sectoral investments, one must take climate change as starting point for a new, offensive spatial strategy, in which the spatial planning of the Netherlands will be judged on climate resilience and sustainability.*
>
> (VROMraad, 2007)

The Netherlands (VROMraad, 2007) recognized climate change as an actual and urgent challenge. The text box shows the relevance of the study program Climate & Management as stated by the national main advisory board for spatial planning and the build environment. Both climate change mitigation and adaptation were crucial issues in this sector.

Naturally, construction companies and government agencies and planning institutes working in the built environment were contacted. It appeared that most of them were very interested in a new program that focused on climate change challenges for the build environment and spatial planning. New young professionals, who have sustainable development as their DNA, would be warmly welcomed in the build environment sector. However, in practice, this kind of professionals was not yet around at the labor market. Hence, this study program would be a frontrunner, meaning also that the program would not exactly know what kind of jobs the future students were going to apply for. Despite this uncertainty, the initiators of program at THUAS decided to proceed as so many employers were very enthusiastic about this profile.

Another important issue was recruiting the potential students. Studies were carried out on the number of potential students that could be interested and actually subscribe to the program. These studies revealed that the potential number of students was 95-149 students/year (Stoltenborg, 2008).

After the program started, it was only able to attract 20-40 students per year. Analysis showed (Schuurman, 2011) that the marketing message could be better: the recruiting message had been rather focused on alarming on climate change. Instead it should more focus on chances and possibilities for mitigation and adaptation in the built environment. It also appeared that the program attracted two kinds of students: the ‘career beta’, being both science and career focused, and the ‘human focused engineer’, that aims at helping through engineering. That helped to focus the communication of the program even better.

**Trends & improvements**

The program firstly focused on climate adaptation and mitigation in the built environment. Later, corporate social responsibility was added. Nowadays, the challenge is to include the concept of circular economy (MacArthur Foundation, 2016). Not only are these subjects offered as theory (a course), 40 % of the curriculum, but they are especially integrated in the projects, 60 % of the curriculum.

Initially, the program’s DNA was climate change and sustainable development. Gradually, it was transformed into climate change, sustainable development and circular economy. However, the structure of the curriculum remained the same: 40% courses, 60% projects. The curriculum was adjusted within the existing structure and moreover, and maybe more important, teachers should be updated on the concept of circular economy. It should become their new DNA.

Traditionally, in higher education it was sufficient to educate students to become specialists and provide them with a few general skills (writing, presenting). However, this was often criticized as the experts should be better equipped to understand each other’s perspective and design integrated solutions. Training T-shaped professionals (Kelley and Littman 2005) has been suggested in order to train professionals that both acquired sufficient general knowledge to enable them both to develop integrated solutions and to have sufficient expertise to contribute to the expertise base of project teams.

As Sustainable Development is a globally defined problem, it diffuses into various more specific articulations (non-polluting, efficient, recyclable, renewable, etc.) if this concept is used for concrete action (van Lente and van Til 2008; Mulder et al. 2011). However, providing student with basic knowledge and skills related to various specific articulations of Sustainable Development is too much. Hence, a T-shaped engineer should be trained according to an articulation of Sustainable Development (Climate change adaptation and mitigation) and wide knowledge of aspects of a specific sector (spatial planning and build environment).

For Climate & Management the T-shaped professional means a specialist who is able to cooperate with other specialists and who is continuously learning, lifelong. Until now, the interdisciplinarity of the program was mainly organized within its own curriculum (projects related to e.g. living with water, energy transition and sustainable mobility).

For the coming years, the new challenge will be to incorporate interdisciplinarity by having in part a joint curriculum with architecture, civil engineering and facility management. The program aims to do so by creating ‘urban labs’. In these labs, located in relevant urban neighborhoods, students work on local assignments brought in by e.g. housing companies, municipalities or water boards. First year students up to fourth year students and graduates, from different study programs will be involved in working on the joint assignment, not only for one term, but continuously. Each group works on a part of the assignment. However, these groups will have to cooperate (=interdisciplinarity) to optimize their results.

The last trend which will be discussed here is on project education. Formerly, teachers came up with fictional projects, which would be close to reality. Nowadays, more and more, they include real assignments by real employers. In the near future, the next step will be co-creation with employers to get an even more realistic experience. Employers will be involved in these urban labs, providing experience and possibly tools, devices and machinery. Cooperation with students on assignments relevant to society as a whole is appreciated by many companies. All stakeholders will be involved: in fact students are cooperating for real in their field of expertise, while they are still at university.

**Results of the program**

After 7 years of relatively few incoming students (table 1), the program started to grow since 2014. As mentioned earlier, it took a while before the marketing and communication was in place. Furthermore, in recent years sustainable development and climate change are rising again on the political and societal agendas. Another factor might be that the program’s name changed from Climate & Management to Spatial planning in 2015.

| Year | 07/08 | 08/09 | 09/10 | 10/11 | 11/12 | 12/13 | 13/14 | 14/15 | 15/16 |
|---|---|---|---|---|---|---|---|---|---|
| Incoming students | 15 | 30 | 18 | 45 | 32 | 31 | 36 | 58 | 59 |

*Table 1: Amount of incoming students per year*

The program is being positively valued by students. Three years in a row (’13, ’14, ’15) the program was entitled to carry the name of “Topopleiding”, meaning top study program. This is based on the National Students Inquiry (table 2).

| | Clim. & Man. | THUAS | National |
|---|---|---|---|
| Study program in general | 4,17 | 3,79 | 3,83 |
| Content | 4,02 | 3,73 | 3,75 |
| Skills and practical research | 3,91 | 3,58 | 3,61 |
| Teachers | 4,09 | 3,57 | 3,64 |
| General atmosphere | 4,93 | 3,95 | 4,01 |
| Would recommend the program | 4,28 | 3,92 | 3,99 |

*Table 2: Results National Students Inquiry 2015 (scale 1 to 5)*

Table 2 shows a higher rate on all aspects, compared to The Hague University of Applied Sciences and the national average. Especially the general atmosphere score is exceptionally high. This possibly represents the high involvement of students and the small distance between teachers and students. Highly involved students as students specifically choose this program because of sustainability. The small distance between teachers and students is partly caused by the size of the program, but also caused by the teachers' attitude, which is focused on the personal development of the individual students.

Some quotes from the HBO Keuzegids, hence view of the students, over the years:

*'Students find a well-structured program, taken care of by good teachers, who properly prepare the students for their career and who pay much attention to their competences.' (2013)*

*'The high students inquiry score is based on the amount of contact hours, content, quality of teachers, skills, good preparations for their career and communication.' (2014)*

Employers in general are very positive about the communication capacities of the graduates. They confirm that graduates are capable to collaborate, to involve stakeholders, to give proper presentations, while always taking sustainable development as a starting point. The latter is being appreciated especially because the graduates know sustainable development never comes alone: one should always implement sustainability together with other initiatives, which requires good networking capabilities. Hence, the T-shaped professional.

Quotes graduates:

*'I feel I have an advantage over university Master students, because of my experience in the working field and my competences like teamwork and presenting.'*

*'Because of Climate & Management I have an intrinsic motivation on sustainability, which helps me to create support for whatever sustainable goal I have.'*

*'Partly because of the network I was able to create during my study, I am now self-employed.'*

Three interviews with graduates indicate that the added value of Climate & Management is in its competences. Presenting, teamwork, involving stakeholders, process management, it all contributes to the profile of the graduates. Furthermore, employers praise the connections with the working field: Real clients in projects, teachers who open their network to be used by the students for e.g. internships.

**Lessons**

Three lecturers that were engaged in creating the program agree that in order to fully implement sustainable development in a study program, it's better to start a new one. Sustainable development is an interdisciplinary issue, which never comes alone. It should be integrated into all elements of a study program, to become the program's DNA.

This brings up the first crucial issue: human resource management. The program has an active human resource management. Sustainable development should be in every employee's DNA. Everything they do, think and represent should be based on the concept of sustainable development, as defined by Brundtland et al (1987). Ideally, future teachers give a few guest lectures to get acquainted and sense whether the working environment suits them well. This possibly results in joining the team, preferably part-time, still working partly in the field in order to be sensitive to new issues and requirements.

The team is characterized by collective learning (Castelijns et al, 2009) (Lodders, 2013). Everybody is willing to give and receive feedback and the team quickly adapts to new circumstances. If a team member is not able to go along, this will be discussed. If problems continue, this will result in quitting the cooperation. Naturally, there a normal legal issues involved, but the philosophy of (the organization of) the program should be leading.

The close cooperation with employers is another important factor. Employers were very much involved in creating and developing the program, so trends could be identified and adjustments could be made quickly. During the last 9 years, it was important to keep an eye on these trends. Two approaches helped to do so. One is to use external lecturers for courses. These lecturers came in once a year to teach their course. These professionals add value to the program by teaching state of the art knowledge, and keep the program updated on actual trends. The second way is to do real life projects as a major part of the education. Each term contains of 15 ECTS, of which 9 ECTS are project based. These projects do have a real client with a real question. The learning goals per term are fixed, but the project, the tools and the criteria can change every year, depending on the project (see text box). The project client does not need to spend much time: he needs to properly formulate his question, needs to do a kick off presenting the case and needs to be present at the final presentation by the students. Some clients like to go to intermediate presentations to keep an eye on student progress. One way to make sure the client gets something out of the project is to use parallel student groups: If some groups do not deliver quality, some other groups will.

**Example of flexible projects: sustainable urban development project**

This is a ten week project for second year students. The assignment was and is: make the existing (re)development plans more sustainable, but not more expensive.

In the beginning it was about urban development; from greenfield to residential area. The client was a national bank. After two years, the client withdrew suddenly, just before the project started. Using the teachers' network (most of them are part-time working in the field), in no time a new client was found: an urban developer, specialized in finance.

Using a clear term structure (9 ECTS project, 3x2 ECTS courses) helps students to perform. But how to be able to quickly adapt to changing circumstances in the working field? In our educational system, projects were updated every year, which worked out really well. Using lecturers from the working field, to teach specific courses, as described above, was also a good way to keep the program updated with changing demand issues. In addition, SD programs have to prepare students for working in an ever changing world as well. At the same time, the need for T-shaped professionals is growing. These professionals need to acquire both sufficient general knowledge to enable the graduate to develop integrated solutions for 'sustainable development problems' and to acquire sufficient specific expertise to contribute sufficiently to the expertise base of a project team. One of the used competences, 'learn to learn', is therefore central in the program.

## Conclusion

In this paper we described a highly successful BSc program Climate and Management. The success is shown by surveys among graduates, students and employers. It is also reflected in the growing number of new students, and in external reviews of the program.

We conclude that the success of the program is due to its core target: educating a T-shaped engineer in the field of spatial planning and build environment.

However, success in training T shaped engineers is not self-evident. Success depends on:

- A committed teaching staff, that aims at collective learning. The philosophy of (the organisation of) the program should not be risked by teaching staff members that do not share it.
- An extremely good network of the program that ensures that alumni are educated in regard to relevant issues, and that the program is regularly updated
- A clear program structure and organisation that allows new issues to enter the program

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# Integration of Sustainable Development in Education – Motivating a Change

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## Abstract

As part of a strategic initiative at KTH to increase focus on environment and sustainable development (ESD), a university-wide project on "Integration of ESD in the Educational Programs at KTH" was initiated in 2012. To ensure continuous work with integration of sustainability in all educational programs, the project has focused on two complementary strategies: evaluation of the programmes' efforts and providing tools and support for all Program directors and teaching staff to achieve the set goals. The evaluation process was conducted in several steps, from schools' self-assessment of the fulfilment of the learning outcomes on ESD stated in the Swedish Higher Education Ordinance, to the creation of action plans (by all schools) for the development and integration of ESD objectives in all educational programmes, and finally a follow-up of the programmes' progress within the area.

To support the process, several tools and inspirational activities have been conducted. The Swedish Higher Education Ordinance's learning outcomes are considered broad and difficult to interpret by the majority of the teaching staff and therefore a clarification of the overall learning outcomes was developed for implementation on both the course- and programme levels. Also, a toolbox containing definitions and good examples of learning activities for integration of sustainable development in higher education was developed and launched as an open website. The project has been involved in the development/support of three course modules that can be implemented in all educational programmes and several events have been organized on teaching activities with inspiring talks by teachers from KTH and colleagues from other universities. In order to facilitate further education of the teaching staff, a pedagogical course on "Learning for Sustainable Development" was developed as an effort of two schools at the university in collaboration with the project leaders. Throughout the process, the Program directors and teaching staff involved in course design have been continuously in contact with the project leaders regarding any ideas or for support in introducing or integrating ESD in the curriculum.

This presentation will focus on the results from the follow-up and the tools that were provided to support Program directors and teaching staff during the process of integration of ESD in the educational programmes at KTH. The results show that several programmes have improved their integration of ESD suggesting that the combined strategy of support and evaluation has been successful.

# 1 Introduction

## *1.1 Background*

One of the most important factors in modern higher education is to assure that graduates have deeper knowledge about present and future challenges as well as the necessary tools they need to be able to contribute to a sustainable society. KTH's (Royal Institute of Technology) long-term strategy, Vision 2027 (KTH, 2011), stresses that the engineers and architects that graduate from the university must have a distinct focus on sustainability. This is also in accordance with the overall learning outcomes set by the Swedish Higher Education Ordinance, that has prescribed a number of learning outcomes for engineering and architect educational programs including two with clear relevance for environment and sustainable development (ESD).

In 2011, the university performed a self-initiated Education Assessment Exercise, where panels of external experts were invited to review all of the educational programs at the university. The results of the evaluation pointed out the necessity of a higher degree of integration of sustainable development on the program levels. In 2012, the "Integration of Environment and Sustainable Development in the Educational Programs at KTH" project was initiated to launch and facilitate activities within the educational programs on the overall level. The aim of this paper is to describe the project's and other related activities, and progress to date concerning the integration of sustainable development in educational programs at the university.

## *1.2 The management structure, leadership and organisation*

KTH is Sweden's oldest and largest technical university. The university is organized in ten different schools that are divided into departments and divisions. The schools are responsible for the educational programs.

The project "Integration of Environment and Sustainable Development in the Educational Programs at KTH" is part of a larger project, KTH-Sustainability, which was established in 2011 (Finnveden et al, 2016). The main project plan was approved by the President of the university and a Vice President for Sustainable Development was assigned as the leader of the overall project. A steering group for the project called the KTH-Sustainability council was also appointed. The council, chaired by the Vice President for Sustainable Development consisted of six teacher representatives appointed by the Faculty Council, two student representatives appointed by the student union, and the environmental manager. The focus of the overall project is on the core activities at the university, containing goals and activities to be undertaken in education, research and collaboration, and the work is overarching and includes all schools. The project is closely connected to the environmental management system, providing a feedback system of continuous achievements and improvements (c.f. Holm, T. et al, 2015; Staniskis, J.K. and Katiliute E., 2016).

As a part of the environmental management system, the university established environmental goals for the period of 2013-2015 and sustainable development goals for the period of 2016-2020. The environmental goals for education were:

- KTH shall work actively to increase teachers' and students' knowledge of and involvement in issues relating to the environment and sustainable development.
- All of KTH's educational programmes should report on how they integrate and develop environment and sustainable development in education in accordance with the Swedish Higher Education Ordinance

The new sustainable development goals for education are:

- KTH shall increase all employees' and students’ knowledge of and involvement in issues relating to sustainable development.
- Sustainable development shall be integrated into all educational programs at all levels so that students can contribute to the sustainable development of society after graduation

The goal of the above mentioned project is to support these goals.

### *1.3 Strategic approach*

Early on, top management decided that sustainable development should be integrated in educational programs. However, how this integration should occur was not prescribed. It was the responsibility of the schools and Program Directors to choose the best course of action. In other words, no decisions for a minimum number of credits or specific courses were made. Instead, this has been addressed through dialogues with Program directors and teaching staff without providing any uniform solutions, such as specific courses, to assure that integration of sustainable development is linked to subjects that are essential within the specific program and provide relevance for the future application of the skills. This has resulted in different solutions being developed at different educational programs.

The approach to assure integration of ESD in educational programs has focused on two complementary strategies: evaluation of the progress of integration of sustainable development on the program level and providing tools and support for Program directors and teaching staff to achieve the goals set by the university. The support is provided through a number of different activities, for example as “coaching” on individual or group levels as well as communicating contact information on teacher resources and expertise available that could facilitate the relevant approach for that specific course or program. It was recognized that some of the teaching staff were troubled with interpretation of the overall learning outcomes set by the Swedish Higher Education Ordinance, therefore one of the first activities within the project was to develop specified learning outcomes as a proposed interpretation relevant to all of the educational programs at the university and as valuable tools for evaluation of the progress of integration of ESD on both program and course levels. Some of the barriers to integration of the ESD were identified as limited teacher qualifications and a problem to extend an overcrowded curriculum. These findings are in accordance to challenges identified at several universities (Læssøe, J. et al, 2009). Therefore, several tools were developed and proposed to the Program directors to facilitate the fulfilment of the goals set by the university.

## 2 Evaluation process

The evaluation process was designed to continuously promote and verify the progress of integration of environment and sustainable development in all engineering and architect programs. In 2012, all programs were given the assignment to conduct a self-assessment of fulfilment of the ESD learning outcomes stated in the Swedish Higher Education Ordinance as a preparatory exercise prior to the evaluation by the Swedish Higher Education Authority. In the self-evaluation the schools were asked to describe the program’s learning outcomes related to ESD, which courses support the learning outcomes of the programs, examples of examination, the level of progression etc. The schools were also asked to specify the need of further support that could be provided to the different programmes to improve the fulfilment of the learning outcomes. The self-assessment resulted in deep analysis of the ESD content in the different programs and provided a starting point for continual discussions about the implementation of ESD related topics in education.

The self-evaluation reports were used as basis for discussions in the following dialogue with the Deans of the Schools and the Directors of First and Second cycle education at all schools. These discussions resulted in setting up of action plans for integration of ESD objectives in the educational programs at each school. The original action plans were set for 2013-2015; some schools revised their plans during 2014. The action plans are part of the environmental management system at the university and thus followed up yearly.

During 2015, a follow-up on the progress in fulfilment of the learning outcomes on ESD stated in the Swedish Higher Education Ordinance, goals set in the action plans as well as the overall environmental goals set by the university (2013-2015) was conducted as a three step procedure. First, all engineering and architecture programs turned in a survey containing courses in the programs that contribute to different learning outcomes, then the survey was evaluated and interviews with the Program directors were performed based on the information in the surveys. Thereafter all of the information was summarized in a short report and submitted to the Directors of First and Second cycle education at each school. The interviews were conducted as a dialogue where both the current level of integration and future development needs were discussed.

## 3 Tools for integration of environment and sustainable development

### *3.1 Specified learning outcomes*

Early during the evaluation process and discussions with teaching staff it became apparent that the learning outcomes related to environment and sustainable development stated in the Swedish Higher Education Ordinance are sometimes perceived as rather general and difficult to apply, especially on the course level. Therefore, in 2012, a proposal defining the overall learning outcomes as ten specified learning outcomes was presented to the Faculty Council which decided that they should be seen as advisory on the university level (Finnveden & Strömberg, 2013). The learning outcomes were thereafter evaluated in discussions with the Program directors and during the self-evaluation in 2012. The received feedback resulted in development of a revised version containing eight specified learning outcomes that were in 2015 decided to be advisory clarifications for program and course development by the Faculty Council. The proposal is meant to be general and relevant to all engineering programs and is a valuable tool in the evaluation process on the program level. The revised version has also been discussed during the follow-up interviews in 2015 giving further insight in the usefulness of the specifications.

### *3.2 Pedagogical course*

One of the recurrent themes that arose in dialogues with Program directors and teaching staff is that there is a high need for further education of the teaching staff and educational leaders on how to teach topics related to ESD. An initiative was taken to develop a new pedagogical course for university teachers; "Learning for Sustainable Development (4.5 ECTS)". The aim of the course is that teachers, based on their own subject, should be able to integrate questions on sustainable development in their teaching so that the students, during and after their education include their integrated knowledge and reflections in the subject sustainable development. The course was developed in 2012 as a joint effort between two schools, the School of Industrial Engineering and Management and the School of Education and Communication in Engineering Science. This course was further developed in 2013 with support and co-financing from KTH-Sustainability. So far, approximately 80 teachers have attended the course during the 5 occasions it has been offered. As a direct result from the ideas developed and discussed during the pedagogical course, at least three educational programs at different schools have implemented integration of ESD on the program level.

### 3.3 Toolbox

In order to provide tools for both the teaching staff and the students to integrate and work with issues related to sustainable development in education, a toolbox for integration of sustainable development in higher education was developed (Toolbox – Learning for Sustainable Development, 2013). The toolbox is published as an open website; this has resulted in attention from other national universities, and has initiated discussions and suggestions for further development of the tools. The design of the toolbox builds on the philosophy of constructive alignment (Biggs and Tang, 2007), aiming at illustrating good examples of how to set up learning outcomes, teaching activities and different methods of examination in relation to sustainable development. The idea behind the toolbox is to provide inspiration and examples of best-practice from within the university and beyond to facilitate teaching ESD on all levels of higher education. The contents and design of the toolbox have been revised during 2013-2015 and new content and literature are continuously added.

### 3.4 Meetings and seminars

Several seminars and events on integration of sustainability in education with national and international guests have been organized to create inspiring environments that promote discussions and exchange of experiences. Seminars on social and economic sustainability were arranged due to an expressed need by Program directors for deeper understanding of the definitions of social and economic sustainability. In 2014 and 2015 a KTH-Sustainability Education Day was organised, during which the teaching staff addressed possible ways of integrating sustainable development both at course and program levels. Inspiring talks were held by teachers from the university, invited colleagues from other universities (Chalmers University of Technology and UPC Barcelona Tech) and by companies that could correlate the engineering education to the needs of the society. The participants shared their experiences and ideas with others and found possibilities for future collaborations. Several events are also planned for 2016 as many have expressed a wish to participate in meeting/discussion arenas on different levels and with a focus of various topics

### 3.5 Course modules

In order to assist integration of ESD in education, two different modules were developed and one was supported. These modules (1-1.5 ECTS) can be implemented directly in existing courses, either as they are or after modifications, assuring relevance for the specific core subject.

A course module focusing on environmentally driven business development was developed in collaboration with a technical consultant company (ÅF). This module is comprised of lectures, group discussions and a hand-in assignment. One of the most appreciated features of this module is that the students spend part of the time at the consultant company, being introduced to the real issues companies are facing. The course module is currently implemented in seven educational programs at different schools.

The teaching staffs have expressed a concern on difficulties to integrate social sustainability on course- and program levels (Björnberg et al, 2015). Therefore, a course module focusing on social sustainability was developed during 2014. The module consists of two parts: a generic part that could be included in any programme and a more subject specific part, which is of high relevance for a specific programme/course. The module is comprised of lectures, seminars and an examination assignment. The module is implemented in three courses, but during the follow-up interviews a demand from several additional programs was expressed.

A course module on introduction to sustainable development was developed independently from KTH-Sustainability (Dahlin et al, 2013), and has over the years received substantial support and promotion. The module is implemented in several engineering programmes and consists of innovative teaching activities, such as interactive large theatre lecturing and the use of board games (which include preparatory quiz questions and peer-discussion). The course content is largely connected to a new textbook (Dahlin, 2014), yet the module is adjusted to each program and is integrated in different ways in collaboration with the course responsible teachers.

## 4 Results from the evaluation

The results from the 2015 follow-up clearly showed that progress has been made. Significant changes have been made in the majority of programs or concrete plans are in place for development. Currently there are no programs that completely lack integration of sustainable development. Several programs have developed additional action plans on further development of ESD aspects relevant to the programs' core subjects. A few programs have gone through (or are in the process of) a complete reconstruction and sustainability aspects have been integrated in several courses. New courses with relevance to ESD have evolved and new educational activities have been developed in existing courses at several schools. One of the remaining big challenges is assuring the progression throughout the 5 years of education, especially since the students studying on the Master level have different backgrounds.

During the interviews, several Program directors explicitly mentioned the positive effect of the different evaluations that have been conducted, making them a tool for the analysis of the progress and incitement for continuous improvement. An interesting observation was that most of the discussions on integration of sustainability in education were positive and the subject was perceived as a natural/necessary part of the education. This is a very positive development compared to the first meetings during 2012-2013.

The pedagogical course has provided insights in the different possibilities of teaching and learning sustainability and has inspired teachers to try various learning activities and methods of examination. Some of the initiatives developed during the course have already been implemented or underway.

One of the most important factors for the progressive work on integration of sustainable development is that the leaders of the schools support Program directors, that this work is prioritized and that resources are allocate for the initiative. The support from the leaders of the university is also of high importance if changes are to be realized on the school levels. It gives the progress the necessary drive. In 2012, top management stimulated the development of educational initiatives related to sustainable development by offering funding for projects. Some of the projects that applied received sizeable funding (approximately 100.000 euro). This funding supported the development of new courses including the first version of the pedagogical course. The effects of this funding support are still visible today.

A general observation is that the commitment from KTH-Sustainability has been a key factor in the integration of sustainable development in educational programs. The support has been appreciated and continued support has been requested. KTH-Sustainability has also offered opportunities for seed funding of educational projects (approximately 10.000 euro).

## 5 Defining the future

The project will continue for at least another three years, but the approach will be adjusted to further develop a more supportive role, somewhat removing the evaluation aspects. This change was suggested by the external evaluation panel that assessed the overall project KTH-Sustainability in 2014 (Holmberg et al, 2015). All of the schools at the university are setting up new action plans for continued integration of ESD in the educational programs in accordance with KTH's new sustainability goals for the period of 2016-2020. The action plans will be part of the environmental management system and followed up yearly during audits. This will assure continuous progress and give opportunity for a more coaching role towards the implementation of the goals.

There is also an aspiration that some of the work regarding integration of sustainable development on the course- and program level can be driven by the teaching staff within the schools and programs. Therefore there is an ambition to build and support teams of teachers at every school. These teams will focus on improvements on the program levels and be able to assist the teachers within the core subjects in the programs. It is also of high importance that the teaching staffs have opportunities for further education in teaching sustainability; therefore, the pedagogical course "Learning for Sustainable development" will continue to be of high priority for continuous development.

The project will also continue to create inspirational environments for teachers and leaders within education to discuss the challenges and exchange ideas and experiences. So far, the focus has been on assuring integration of ESD during the first three years of education. Now the work will continue with implementation on the Master- and Doctoral levels.

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# Reasons behind why some courses in environment and sustainable development are not appreciated by students and why some are

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## Abstract

Engineers are important actors in a transition towards a sustainable society. In order for engineers to gain relevant competences for such a transition, courses in environment and sustainable development must be appreciated by students. One success factor can be to motivate students with relevant topics for their specific engineering discipline. A challenge for teachers is to choose relevant topics and to keep topics up to date, for example, circular economy is a rather new concept that can be relevant for some engineering disciplines while green chemistry can be relevant for others.

Results from course evaluations show that courses in environment and sustainable development in average are not appreciated by students to the same extent as courses in general at Chalmers University of Technology in Sweden. As a part of course evaluations, students answer an electronic questionnaire after each course. One of the questions is "what is your overall impression of the course", and it is possible to give a score from 1 (very poor) to 5 (excellent). The average results for the students' overall impression of the 24 courses in environment and sustainable development at Chalmers in 2014/15 was 3.2, which is lower compared to the average results for all courses at Chalmers, 3.8.

In this study, we analyze reasons behind why some courses in environment and sustainable development are not appreciated by students and why some are, with the objectives to answer the questions:

- Are there any common features among the courses that get a low or high evaluation grade, respectively? And especially, how well do the students perceive that the topics of the courses are connected to their engineering disciplines?
- Which mistakes are done in the courses that get low evaluation grades, and should be avoided?
- What can we learn from the courses that get a high evaluation grade?

We have analyzed the results in the student questionnaires, and especially the free text answers, for the nine courses in environment and sustainable development that got a lower grade than 3 and the six courses that got a higher grade than 4 in 2014/15.

Some reasons for low evaluation grades are when students perceive that the topic is not relevant for their engineering discipline or that learning of relevant competences is not supported. Teachers have to be aware of this and continuously work on improving their courses in this respect.

# 1 Introduction

Engineers are important actors in a transition towards a sustainable society (Hanning et al., 2012). In order for engineers to gain relevant competences for such a transition (Segalàs et al, 2009), courses in environment and sustainable development must be appreciated by students. One success factor can be to motivate students with relevant topics, which are dependent on engineering discipline (Enelund et al., 2012). A challenge for teachers is to choose relevant topics and to keep topics up to date, for example, circular economy is a rather new concept that can be relevant for some engineering disciplines while green chemistry can be relevant for others.

Results from course evaluations show that courses in environment and sustainable development in average are not appreciated by students to the same extent as courses in general at Chalmers University of Technology in Sweden. As a part of course evaluations, students answer an electronic questionnaire after each course. One of the questions is “what is your overall impression of the course”, and it is possible to give a grade from 1 (very poor) to 5 (excellent). The average results for the students’ overall impression of the 24 courses in environment and sustainable development at Chalmers in 2014/15 was 3.2, which is lower compared to the average results for all courses at Chalmers, 3.8. And the percentage of courses in environment and sustainable development that got an average result lower than 3 were 38%, which is a larger share compared to all courses at Chalmers.

Hence, there is a need to understand the reasons behind why courses in environment and sustainable development in general get a lower score to be able to make improvements.

Reasons behind why some courses in environment and sustainable development are not appreciated by students and why some are appreciated are analyzed in this paper, with the objectives to answer the questions:

- Are there any common features among the courses that get a low or high evaluation grade, respectively? And especially, how well do the students perceive that the topics of the courses are connected to their engineering disciplines?
- Which mistakes are done in the courses that get low evaluation grades, and should be avoided?
- What can we learn from the courses that get a high evaluation grade?

# 2 Method

The method includes three parts:

1. selection of courses to analyze,
2. analysis of the scores given by students for these courses in the course evaluation questionnaire, and
3. analysis of the free text answers given by students for these courses in the course evaluation questionnaire.

## *2.1 Selection of courses*

There is a local course requirement at Chalmers that all students should take 7.5 ECTS in environment and sustainable development, during the first three years of their education, in order to get their degree (Enelund et al., 2012). There is a variety of such courses at Chalmers, which are developed for different study programmes in architecture, engineering, and naval engineering (Chalmers University of Technology. 2016). The study programme directors mark the courses that fulfil this requirement in their programmes. The courses that are analyzed in this work are the courses that include 100% environment and sustainable development according to this marking of the study programme directors.

## 2.2 Course evaluation questionnaire

An electronic course evaluation questionnaire is sent to the students after each course. The questionnaire includes some standard questions that are always included, see Table 1. It is also possible for the students to write free text answers to the questions.

Question No. 7 is about the student's overall impression of the course. An average score lower than 3 is here considered to be a *low student satisfaction*, and higher than 3.5 as *high student satisfaction.* The courses with either low or high student satisfaction is further analyzed and the average scores for the questions is presented and discussed.

Table 1: Questions in the electronic course evaluation questionnaire.

| No. | Question | Range for scores 1 | Range for scores 5 |
|---|---|---|---|
| 1 | Prerequisites: I had enough knowledge to be able to follow the course | Disagree completely | Agree completely |
| 2 | Intended learning outcome: The intended learning outcome clearly describes what I am expected to learn in the course | Disagree completely | Agree completely |
| 3a | Learning: The course structure (as divided into lectures, exercises, lab sessions, simulations etc.) is appropriate in order to reach the intended learning outcome of the course | Disagree completely | Agree completely |
| 3b | Learning: The teaching worked well | Disagree completely | Agree completely |
| 3c | Learning: The course literature (including other course material) supported the learning well | Disagree completely | Agree completely |
| 4 | Assessment: The assessment (including all compulsory elements, exams, assignments etc.) tested whether I had reached the intended learning outcome of the course | Disagree completely | Agree completely |
| 5 | Course administration: The course administration (information during the course, course memo, course homepage etc.) worked well | Disagree completely | Agree completely |
| 6 | Workload: The course workload as related to the number of credits was... | Too low | Too high |
| 7 | Overall impression: What is your overall impression of the course? | Very low | Excellent |
| 8 | How has cooperation with the teachers of the course worked? | Only free text answer | |
| 9 | If the course has contained group activities (lab sessions, group work, projects, or other types of cooperation between students): How have group roles and cooperation between students worked? | Only free text answer | |
| 10 | What is most important to preserve for the next round of this course? | Only free text answer | |
| 11 | What is most important to change for the next round of this course? | Only free text answer | |

## 2.3 Analysis of free text answers

The standard questions in the questionnaire cover just some of the issues that can have influence on the students' overall impression and satisfaction of a course. The free text answers can give some indications on other issues that can have influence on the students' satisfaction. The free text answers are analyzed to find out about which these other issues can be and how they vary between the selected courses.

There are some issues that can be considered to be especially challenging for courses in environment and sustainable development in engineering study programmes. The issues that are listed in Table 3 have been identified based on earlier experiences about challenges for such courses and on students' comments in the free text answers. In Table 3, the issues are described both as challenges, which can cause negative impact on the students satisfaction of a course, and as opportunities, which can cause positive impact on the students satisfaction of a course.

Table 2: Issues that can have impact on students' satisfaction of courses and which can be especially challenging for courses in environment and sustainable development in engineering study programmes.

| | Issue | |
|---|---|---|
| No. | Challenge (negative impact) | Opportunity (positive impact) |
| 1 | Repetition from high school or other courses at the university;<br>Too easy, low level, shallow | New material;<br>Challenging, deep, useful |
| 2 | Teachers have low competence in environment and sustainable development | Teachers have high competence in environment and sustainable development |
| 3 | Low relevance for the study programme and the profession | High relevance for the study programme and the profession |
| 4 | Unclear and unstructured content; Fuzzy | Clear and structured content |
| 5 | Pessimistic and problem oriented | Solution oriented |
| 6 | Assessment of students' values.<br>Teachers promote their own values. | Students' feel free to discuss their values |

## 3 Results

### *3.1 Students' overall impression of the courses in environment and sustainable development*

There is a large range on the average scores for the student' overall impression of the courses in environment and sustainable development: from 1.89 to 4.15 (of maximum 5), see Table 3. It is a larger share of the courses that has a low score and thus low student satisfaction, i.e. nine course, compared to the share of courses that has a high score and thus high student satisfaction, i.e. six courses.

Table 3: Scores for the overall impression and response rates for the courses in environment and sustainable development at Chalmers University of Technology.

| High score | | | Medium score | | | Low score | | |
|---|---|---|---|---|---|---|---|---|
| Course | Score | Response rate | Course | Score | Response rate | Course | Score | Response rate |
| 1 | 4.15 | 50% | 7 | 3.48 | 58% | 14 | 2.97 | 51% |
| 2 | 4.0 | 40% | 8 | 3.47 | 37% | 15 | 2.88 | 35% |
| 3 | 4.0 | 33% | 9 | 3.35 | 34% | 16 | 2.72 | 58% |
| 4 | 3.88 | 34% | 10 | 3.19 | 38% | 17 | 2.71 | 54% |
| 5 | 3.61 | 40% | 11 | 3.09 | 50% | 18 | 2.67 | 45% |
| 6 | 3.58 | 41% | 12 | 3.09 | 33% | 19 | 2.58 | 58% |
| | | | 13 | 3.05 | 47% | 20 | 2.44 | 42% |

| | | |
|---|---|---|
| 21 | 2.43 | 33% |
| 22 | 1.89 | 55% |

## 3.2 *Quantitative results from the course evaluation questionnaire*

The average scores for the six questions in the course evaluation questionnaire (see section 2.2) for a selection of the 24 courses in environment and sustainable development at Chalmers are presented in Table 4.

Table 4: Average scores for the questions in the course evaluation questionnaire for courses in environment and sustainable development at Chalmers. The grey colours illustrate differences in scores for questions 2-5: white: x>=4, light grey: 3.5=< x<4, middle grey: 3=< x<3.5, dark grey: 2.5=< x<3, black: x<2.5

| Question<br>Course | 1 | 2 | 3a | 3b | 3c | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| 1 | 4.68 | 4.28 | 4.38 | 4.30 | 4.02 | 4.23 | 4.55 | 3.17 |
| 2 | 4.94 | 3.82 | 4.50 | 4.33 | 3.33 | 4.22 | 3.94 | 2.78 |
| 3 | 4.70 | 4.10 | 4.10 | 4.20 | 3.75 | 4.20 | 4.20 | 2.85 |
| 4 | 4.39 | 4.18 | 4.09 | 3.97 | 3.36 | 4.21 | 3.91 | 3.70 |
| 5 | 4.84 | 4.61 | 4.10 | 3.78 | 3.59 | 4.18 | 4.59 | 2.88 |
| 6 | 3.94 | 3.74 | 3.68 | 4.05 | 3.37 | 3.53 | 4.17 | 3.61 |
| 14 | 3.90 | 3.59 | 3.14 | 3.21 | 2.39 | 3.34 | 3.59 | 3.24 |
| 15 | 4.58 | 3.76 | 3.45 | 3.16 | 2.52 | 3.36 | 3.91 | 3.12 |
| 16 | 4.44 | 3.18 | 2.72 | 2.94 | 2.89 | 2.78 | 2.56 | 4.39 |
| 17 | 4.86 | 3.33 | 2.95 | 2.29 | 2.90 | 3.38 | 1.76 | 3.29 |
| 18 | 4.66 | 3.32 | 3.47 | 3.00 | 2.07 | 3.13 | 3.58 | 3.68 |
| 19 | 3.67 | 3.21 | 2.85 | 2.85 | 2.64 | 2.76 | 3.47 | 3.72 |
| 20 | 4.49 | 3.26 | 2.93 | 2.65 | 2.61 | 3.02 | 2.33 | 3.53 |
| 21 | 4.22 | 3.09 | 2.83 | 3.00 | 2.04 | 2.83 | 3.09 | 3.65 |
| 22 | 4.00 | 3.21 | 1.89 | 1.86 | 1.46 | 2.50 | 2.56 | 3.19 |

The average scores for question No.1 about prerequisites show that most students think that they have had enough knowledge to be able to follow the courses. Thus, the courses have not been on a too high level. There is no correlation between the average scores for this question and the students overall impression of the course.

There seems to be a correlation between the average scores for question No. 2 about intended learning outcomes and the overall impression of the courses. However, all average scores for question No. 2 are above 3, which is an ok result.

The average scores for questions No. 3 (a-c) about teaching, and No. 4 about assessment, can work as an indication for the students' opinion about how well aligned these parts have been, i.e. how constructively aligned the courses have been (Biggs & Tang, 2007). There is a strong correlation between the average scores for these four questions and the students' overall impression of the course.

The tendency for the average scores for question No. 5 about administration, is that courses with a high overall impression has a very good administration. However, a good administration is not enough to get a high overall impression. The course with the worst administration (No. 17), according to the students, has not got the lowest overall impression.

Most of the students think that the work load (question No. 6) in the courses has been ok, i.e. a score between 2.5 and 3.5. Six courses has had a too high work load, i.e. between 3.5 and 4, and one course (No. 16) has had a very high work load, i.e. above 4.

Interesting to notice is that the average score for question No. 3c, about course literature and other course material, in general has the lowest value (for questions No. 2-5) for all courses, except for the courses No. 16, 17 and 20 for which question No. 5 about administration is lower. When reading the free text answers, there are various reasons for why the students are not satisfied with the course literature: there was none, difficult to obtain, too expensive, not connected to the course content, unnecessary since the rest of the course material covers the content, too easy, too difficult, includes some wrong facts, not enough facts but too much fiction.

### *3.3 Results from the analysis of the free text answers*

The results from the analysis of the free text answers for the selected courses in environment and sustainable development at Chalmers are presented in Table 5. These results must be interpreted in a cautious way since they are just free text answers to questions that are not specifically about the issues that are analyzed here. The results can be underestimations of the students' opinions since there can be additional students who have had opinions about these issue but who has not written any comments. This is especially likely for positive opinions since there is a tendency to write negative comments rather than positive comments. There is also a risk of overestimations of students' opinions since it is possible for each student to write comments at several places in the questionnaire.

Table 5: Share of students (in %) who have answered the course evaluation questionnaire and given either negative (-) or positive (+) free text comments about six complementary issues that can have had influence on the students' satisfaction of the courses in environment and sustainable development at Chalmers. The range reflects the uncertainty about the share of individual students behind the comments, since each student can write comments at several places in the questionnaire. The grey colours are used to illustrate the variations in the share of comments, where the darker colours stand for a larger share of comments.

| Issue => | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Course | - | + | - | + | - | + | - | + | - | + | - | + |
| 1 | 2-4 | 4-6 | | | 8-17 | 2 | 2 | | 2-4 | | | |
| 2 | | | | | | | | | | | | |
| 3 | | | | | | 25 | | | | | | |
| 4 | | 9 | | | 6-12 | 6-9 | | 6 | | | | 3 |
| 5 | 5-10 | | | | | 2 | | | | | | |
| 6 | 11 | | | | | 5 | | | | | | |
| 14 | 3-7 | | | | 7 | | | | | | | |
| 15 | 15-18 | | | | 12-24 | | 3 | | | | 3-6 | 3 |
| 16 | | | | | | 11 | | | | | | |
| 17 | 14-38 | | 5-10 | 5 | 10 | 5 | 10-19 | | 14-19 | | 5 | |
| 18 | 6-16 | | 3 | 3 | 6-9 | | 3-12 | | | | 3 | |
| 19 | 3-6 | | | 3 | 15-42 | 6 | | | 3-6 | | | |
| 20 | 5-12 | | | | 2-5 | | 5-12 | | | | | |
| 21 | 4-13 | | | | | | | | | | | |
| 22 | 4 | 4 | | | 4 | 14 | 11 | | | | 4-7 | 4 |

Most of the courses have got some comments about being too easy or at a too low level (i.e. issue 1). A few of them also got comments about repetition from high school. It is especially two courses (No. 15 and 17) that have got a relatively large share of comments about this, e.g.: “The course has hardly made me learn anything new at all” (No. 15). However, there are also some positive comments especially for course No. 4: “I have learnt a lot”.

There are not so many comments about teachers’ competence in environment and sustainable development (i.e. issue 2). Course No. 17 have got both negative as well as positive comments, e.g.: “I have low confidence in the teachers since they have not showed any major competence within their field”; “I want to keep teacher […] for next year due to his knowledge about concrete analysis of sustainability”.

Most of the courses have got some comments about their relevance for the study programme and the profession (i.e. issue 3). Two of the courses (No. 15 and 19) have got a relatively large share of negative comments, e.g.: “A large part of the content was not relevant for the study programme [..], e.g. the content about overpopulation” (No. 19). Course No. 3 have got positive comments from a large share of the students about guest lecturers from industry who had given a valuable contribution to the course. In the questionnaire for course No. 4, there was an additional question for the students about how well the course had prepared them to work with environment and sustainability issues in their future profession. The average score for this question is 3.2 of maximum 4, which is a positive result.

Some courses have got comments about an unclear, fuzzy, and unstructured content (i.e. issue 4). Two of the courses (No. 16 and 22) have got a relatively large share of negative comments, e.g. “The course feels fuzzy and unscientific, which result in that knowledge is not taken seriously” (No. 22). Course No. 4 got only positive comments, e.g.: “Things that have seemed to be fuzzy became clear”.

There are only few courses that have got comments about that they are pessimistic or problem oriented (i.e. issue 6). Course No. 17 got such comment from a large share of the students, e.g. “The lectures in the beginning were very gloomy and rather prolonged, even though it was interesting and important stuff one did not really manage to listen. One also got completely depressed a couple of weeks, one could notice it on the whole class.”

There are rather few courses that have got rather few comments about teachers who assess the values of students or who promote their own values (issue 6). An example from course No. 15 is: “Personal opinions from some lectures without support from science should be minimized”.

In general, the courses with low student satisfaction (i.e. No. 14-22) have got a larger share of negative comments compared to the courses with high satisfaction (i.e. No. 1-6). However, the combined reasons for students’ satisfaction of courses is given by the scores for the template questions together with the free text answers.

## 4 Discussion and conclusions

In this paper, we have analysed some reasons behind why some courses in environment and sustainable development at Chalmers University of Technology are not appreciated by students and why some are appreciated. The questions in the template for the course evaluation questionnaire capture some important issues that can influence the students’ opinions about courses. There is a clear connection between how well the teaching and learning situations and assessments are aligned with the intended learning outcomes and the students’ overall impression of a course. It is also clear that the students' overall impression of a course depends on how well the administration of the course has worked. These are general issues can are valid for all kinds of courses.

However, there are specific challenges for courses in environment and sustainable development in engineering study programmes that can influence the students' opinions about these courses that are not captured by the questions in the template for the course evaluation questionnaire. Students' free text answers in the questionnaire can give an indication of such challenges. There are especially three challenges that seems to be important for the students' overall impression of courses, and which have got comments in the courses that have been analyzed. The first challenge is to not make the courses to easy and have a too low level. The students want to learn new things at a deep level. They do not want to have repetition from high school. The second challenge is to include a course content that is relevant for the specific study programme and the profession. The students want to have a relevant content for their education. The third challenge is to avoid an unclear and fuzzy content. The students want to learn how they can use this knowledge in concrete situations in their profession.

In order to deal with these challenges, teachers have to adapt their courses to the competences that the students already have from high school. The teachers have to have competences both in environment and sustainable development as well as in the field of the study programme in order to support a deep learning and to include a relevant content for how the students' can use knowledge in environment and sustainable development in their profession. Other mistakes that teachers should avoid are to make the content too pessimistic, but instead make the courses mainly solution oriented, and to assess the students' values, but instead encourage a discussion about values.

The analysis of the free text answers in the questionnaire cannot give very accurate results but can just give indications of the students' opinions for the challenges that have been analyzed. A recommendation to better understand reasons behind students' overall impression of courses in environment and sustainable development is to include additional questions about the specific challenges in the questionnaires for these courses.

An unexpected finding in the analysis of the average scores in the questionnaire is that the average score for the question about course literature and other course material in general has the lowest value compared to all the other questions. It could be interesting to analyze this further to find out if this is a problem specifically for courses in environment and sustainable development or if it is a problem in general for all kinds of courses.

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# Ecological urban vegetable gardens: INEA's lifelong learning Project.

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## Abstract

The Organic Gardens Project began in 2005 and it is framed as a lifelong learning project through educational and recreational activities for seniors, students and unemployed people. This project is supported by the local government of Valladolid and managed by INEA (Instituto Nevares de Empresarios Agrarios: Nevares Institute of Agricultural Entrepreneurs).

Thanks to this project INEA manages 613 organic gardens in the city of Valladolid, divided into five different areas of the city: 183 gardens ($60m^2$ each one) are distributed in different neighborhoods of the city and are given to unemployed and low-income people. Anothers 430 (105 $m^2$ each one) are situated in INEA's farm where the University bulding is (6.2ha of a total of 28ha) and are meant for retirees.

One of the main objectives with the development of this project is to present the organic farming through the care of urban gardens. The innovative aspect of the project is the active participation of every stakeholder in the teaching process. We propose and promote various activities for which we require the active participation of gardeners and degree students. They have to prepare one or more topics from a list proposed by a group of professors. Then they explain it to the audience in small talks or workshops under the supervision of professors. To complement the training other activities are carried out:

1- Lectures are offered by experts in INEA on different topics related to organic and sustainable agriculture, fair trade, responsible consumer habits, etc.
2- Farms and different types of companies (related to ecology and sustainability) are visited.
3- All together we organized a little museum of horticultural products every year, charity markets, etc.

For a proper use of the urban gardens, a set of standards has been stablished which users must follow. In addition there is always a technical team that advises and helps the gardeners to fit the requirements of organic farming.

This is a pioneering project in Spain not only because it is being managed by a private non-profit organization, which promotes the ecological activity and sustainable development but also to encourage active and participatory learning for all ages, namely lifelong learning.

## 1 Introduction

Since the beginning of last century the reasons for promoting urban gardens have been very varied. The first ones appear in the 20's as educational projects in schools and as an aesthetic complement in cities (Pudup , 2008, Rudolf , 1992). Emergency situations caused by the Great Depression in the United States and the I and II World Wars led to crops welfare projects due to food shortage. Since the 70s programs of community gardens have appeared, promoted either by social movements or local administrations for various purposes (Alonzo, 2013; Brown y Carter, 2003; Crouch, 2000; Moskow, 1999; Alaimo *et al*., 2010; Baker, 2004; Borelli, 2008; Corkery, 2004; Freidberg, 2001; Kingsley y Townsend, 2006; Kingsley *et al*., 2009; Perkins y Lynn, 2000; Saldivar-Tanaka y Krasny, 2004; Trinh *et al*., 2003).

In this regard, the United Nations (FAO, 2010) state that urban gardens help fight hunger , poverty , exploitation and hopelessness that can lead to high crime rates, prostitution, lack of childcare and drug use. There are many examples throughout the world. Take just two examples: Young people with a background of robberies or similar crimes in the Mathare slum in Nairobi earn a decent living growing and selling their vegetables; The community gardening program in Bogota, integrates veterans, the elderly, prisoners, the disabled and people with VIH.

There is extensive literature on green areas and plantations in cities and leisure spaces for residents. Chen and Jim, 2008 , pointed out that 65.7 % of people use these spaces for recreation and that young people between 20 and 30 years are the ones who use them less. In addition, cultivation and gardening offer city citizens an activity that pushes them away from their sedentary lifestyle and stressful job conditions in the city (Orsini, 2013; Clayton, 2007). Thus, users of community gardens, in a study of Brown and Carter (2003), held in Philadelphia, noted that entertainment is the main reason for cultivation (21%). For many people, learning to cultivate is the main reason to have a garden (Alonzo, 2013).

From the beginning, the motivation from INEA (College of Agricultural Engineering) to develop the Ecological Urban Gardens Project has been to provide an alternative leisure activity through the use and enjoyment of the garden base don a deep knowledge of the practices and ecological and sustainable treatments.

The original project was aimed at retirees of Valladolid. For this reason we chose alternative methods of learning, more related to leisure than work activity which is the usual process of learning. Nowadays, the project is fully consolidated and has allowed to implement related projects. Besides, the project embrace unemployed and people in situation of social exclusión and the project attempts to answer the transverse interest shown by users, such as, responsible consumption, food quality, etc. and their needs, given the fragile situation of these groups.

## 2 Materials and Methods

The " Ecological Urban Gardens " Project is a social, educational and recreational activity financed by the local government of Valladolid, with an annual contribution of 80,000 euros, but organized and developed exclusively from INEA. The project is aimed at pensioners, unemployed and people in situations of social exclusion.

In 2005 the first 250 urban gardens (105 $m^2$ each one) were created. In the following two years, because of the success of the first campaign, both requests and production, were extended to the current 430 gardens within the estate of INEA. In 2014, 183 orchards (60m$^2$ each one) were created in different areas of the city, taking advantage of unused spaces. Today that number has risen to 200 orchards making a total of 630. In addition, in order to supply fresh products to different social projects carried out in the city, there is also a ecological community urban garden in each area. Each year, gardeners are those who choose the social projects which they want to cooperate with. In the last campaign the projects chosen were: The Food Bank that collects surplus food of shops or businesses to be distributed among the population in need; The Shelter for 15 HIV people Miguel Ruíz de Temiño; The Religious Congregation Martha and Mary which cares for 100 elderly people with very low or nonexistent income and Red Incola, a support organization for the immigrant population in precarious situation which promotes their rights for a decent life.

All the urban gardens have direct access and water on the plot. They are equipped with a chest to store the tools that every gardener received with a hose in the granting of the garden. Every gardener has the freedom to plant the garden according to their abilities, tastes or needs. Over time, the garden reflects the character of every gardener, order and disorder, geometry, type of products and crops. A team of 4 technicians help gardeners and advise them on what they need so as to obtain a good daily development of the project. Besides, there are a few mandatory rules whic are given to each of the gardeners at the beginning of each campaign.

There are many different activities that are promoted by both teachers of INEA, the technicians responsible for orchards and by the users themselves. Among the activities with a marked educational character, different workshops focused on the development and understanding of different ecological horticultural skills that are taught by the gardeners themselves or by INEA students with the help and supervision of the technical managers and certain teachers at the college.

The usual workshops are:

1-Ecological workshop operations in orchards, which focus on the issue of pruning and trellising.

2-The different members of the family Solanaceae and Cucurbitaceae are also covered.

3-The workshop of pests and diseases which disclosed pests and most common diseases in horticultural plants and their related ecological treatments.

4-The workshop of identification eggs and larvae.

5-Poli's corner, where one of the oldest horticulturists helps to recognize medicinal plants and its usefulness and subsequent treatment for infusions.

During the months of May and June, different school visits are received. Students and gardeners, always under supervision of any teacher or technician, respond to the kids' questions, who also are encouraged to perform some activities in the orchard (planting, collection, etc.).

Fortnightly, talks are held with practical demonstrations (whether these are possible) and the most varied topics are treated, always related to ecology and sustainable development: irrigation, fertilizers, pests and diseases, energy saving and efficiency, responsible consumption, fair trade , etc. These lectures are given by students or former students who want to collaborate with us providing their work experience.

Both gardeners and students are encouraged to participate actively in these activities. The technicians speak one by one with the gardeners and propose activities, others activities are proposed by the gardeners; Teachers are responsible for encouraging students, since it is an alternative learning way but very efficient and enjoyable. The interaction between the retirees and the College is one of mutual enrichment: knowledge and experience in equal parts.

There are many other activities, which are not related to teaching only, such as literary contests, the gatherings of brotherhood where meeting points are searched among gardeners, on Fridays afternoon, where you can listen to the most varied discussions; contests of horticultural products, the best dish out of the garden; gardeners voting for the best orchard, etc.

A charity market of ecological orchard products close each campaign. Gardeners donate their products and their work for free and the profits (last year was 4,700 euros ) goes to various charitable projects ( in 2015 the indigenous cultural education in Bedum , Mindanao in the Philippines). This type of action seeks, firstly, money to support charitable purposes, activate the solidarity of the gardeners, publicize the social projects in which we participate, promote the responsible consumption of high quality and high value nutritional and promote the dissemination of the organic gardens project.


Figure 1. Site plan and detail of the 430 orchards grown in the organic gardens project in INEA (Valladolid)

## 3 Results

Since 2007, every year two surveys are carried out to gardeners at the beginning and at the end of the campaign through personalized interviews. The results of the interviews provide us with the necessary information to know what we need to improve for our next campaign.

Of the 630 gardeners, the survey was conducted for a total of 245 of them for a confidence level of 95 %, which represents an error of 4.9 %. And now, some of the most interesting results of the previous campaign (2014-2015) are shown.

50% of the survey respondents had been more than 5 years cultivating the garden and 67% of them were aged between 49 and 70 years. Most of them (52.45%) had come to know the Project through the media of Social Services of Valladolid and 41% of them because of the recommendation of a friend. This fact shows the satisfaction of people with the Project who recommend it to their friends and acquaintances. In fact, 100 % of respondents would recommend participation in the project to someone else. Another significant fact, which reveals the succes of the Project, is that most of them renewed their orchard orchard every year. People who don't renew is because an illnes or because they have found a job, etc, but nothiong related with a bad experience with the Project.

Almost half ofthe survey respondents had primary studies, and a quarter of them had a university degree. In addition, 57.38 % of them said they had cultivated something previously. Most came from the tertiary sector and services, shopkeepers, hotel and education, automotive industry, processing industries and agro-industry and only a small number came from agriculture. Most were employed persons although there were also entrepreneurs (30.33%).

As it happens in other occupational experiences orchards, our gardeners mainly cultivate orchards for leisure, to obtain quality foods and as something therapeutic as well (Table 1). These results offer us very important information to focus the training activities that are organized taking into account the criteria of leisure, socialization among gardeners, learning cultivate, etc. Other reasons also expressed by gardeners coincide with Gross and Lane (2007), and Kiesling and Manning (2010), who showed that the cultivation of orchards was: an antidote to everyday stress, a space to create social relations, a place for recreation with family and friends and where they make connections with other gardeners and also a question of mental and physical health.

Learning to cultivate is only an initial motivation for 44.26 % (Table 1) of the gardeners, but year after year we find  that attendance to the scheduled talks, the increase in the use of the library and the computer room of the College, get bigger throughout the campaign.

The main reasons of retirees to obtain a garden are leisure, stay active and healthy, and own food security. From INEA, we seek users engage with an ecological model  and sustainable culture from their knowledge. A priori both interests appear to diverge, but throughout the campaigns, it is observed that there is a growing interest in the knowledge of plants, ecological pest treatments and energy saving among others.

Tabla 1: Relative frequencies (%) for the initial motivations of the gardeners of Valladolid for urban gardening.

| **Motivations** | **Answers** |
| --- | --- |

| | **Yes** |
|---|---|
| Leisure | 99,18 |
| Health | 98,36 |
| Food Safety | 94,26 |
| Socialise | 90,16 |
| Food needs | 59,02 |
| Curiosity | 50,82 |
| Share hobby with friends | 47,54 |
| Learning to cultivate | 44,26 |
| Nostalgia | 30,33 |
| Contact with nature | 9,84 |

## 4 Conclussions.

The success of Ecological Urban Gardens Project is tested by , i ) the number of continuous years of the project ( 11 years), ii ) the number of gardens ( 630 ) and the volume of products, iii ) the number of new applications received , which increase every year , iv ) the recommendation of the activity by users to their friends and acquaintances ( 41 % ) , v ) the high share of gardeners in organized activities ( 91.8 % ) , vi) the amount of renewal requests ( 96.72 % ) , vii ) the number of continuous years that a gardener has been cultivating his plot (5-8 ).

The work also confirms that the relationship and commitement of a gardener depends on their social and demographic characteristics (Comstock et al., 2010). It is confirmed that provenance and the labour activity sector determine the reasons for each gardener to cultivate the garden.

From the characterization of gardeners made in this paper we intend to organize the plots around their motivations, origin and previous occupation. This organization will streamline the actions, allowing different degrees of attention to the expectations of each. For those who come from the city social care will increase and will place special emphasis on activities that allow the relationship with other gardeners.

For gardeners who come from the secondary sector we focus on cultivation practices, land use, crop morphology, pathologies and their relationship with the environment. For gardeners from rural areas who grow their own crops we promote historical and cultural activities and we want them to be able to exchange their knowledge and experienced.

However, the changing political, economic and social situation could jeopardize the continuity of the projet. In this regard it would be necessary to consider possible alternatives.

We might consider the commercial and economic exploitation of urban gardens so that they could become sustainable. Benefits would be used to fund supplies, consulting, management, costs of land use, etc.

A cooperative system among gardeners could be proposed so that a portion of the products they get from the garden can be used to cover expenses. The destination of these fresh and healthy products could be schools, senior centers and hospitals of administrations promoting projects, closing the cycle of institutional procurement by using the products obtained during the agricultural campaign. We could take advantage of their proximity as another link in the chain for this cooperative system and try to supply orchard goods to restaurants and delis that demand quality and healthier products. In this way, orchard productions should be organized taking into account the possibilities of consumption and the comercial demand. Besides, an appropriate crop rotation should be analyzed ifwe want to provide fresh and alternative products to restaurants or delis.

Another important point is that local governments become aware of the importance of allocating a part of the urban land for horticultural practices as there are a lot benefits for the local population.

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# The pedagogical value of collaborative work and field studies in an Ecology course for engineering students.

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Engineers are often suggested to be important in the process of transition toward a sustainable society, not least as a communicative link between technological development and economy, environmental and social processes. Therefore a greater focus on engineering education concerning sustainability teaching is urgent. However, integrating sustainability in higher education faces many challenges due to the contradiction between traditional structures and values in the academia and the features needed for a new teaching approach enhancing valid teaching in sustainability issues on the university level. (Wieman 2014)

A new pedagogical approach including more active teaching, and a shifting focus from lecturing (passive teaching) to active learning might be needed. Passive teaching still dominates the higher education in many universities and technological

Institutes around the world, although increasing support that "active learning approaches" increases the student's performance and engagement (Freeman, Eddy et al. 2014)

We have studied the outcome of active learning approach and the effect of outdoor and collaborative learning in a course (Ecology and Environmental Science) held for 1st and 2nd year bachelor students in an Energy and Environment Engineering program at KTH, Stockholm during the autumn 2015. The course included traditional teaching in the form of 7 lectures in addition and a more active learning approach consisting of a collaborative work (group work projects) and a field excursion.

The main idea in active teaching is to increase the student engagement in the learning processes. This approach may include problem-based learning, cooperative or collaborative learning. Outdoor teaching is another approach to increase active learning processes. There is strong support for additionally learning effects from collaborative learning (Verenikina 2012, Conejo, Barros et al. 2013) and results from a recent study suggest also a positive trend between outdoor activities and learning outcomes concerning group work skills (Cooley, Burns et al. 2015). However working in group per se does not automatically lead to enhanced learning, and group processes are important for the outcomes of the collaborative learning process (Nussbaum, Alvarez et al. 2009). It has also been debated whether all students or only certain students (for example high-performing or low-performing students) are gained by collaborative teaching (Wass, Harland et al. 2011, Lee, Kim et al. 2015).

We identified 4 potential factors affecting the learning outcomes from collaborative work: 1) Student **engagement** – whether student find the collaborative work engaging or not (see, (Freeman 1996)), 2) **Confidence** – related to engagement is the confidence – do students believe that individual learning will increase with the collaborative work or not? 3) **Preference** – students willingness to work in group work projects in comparison to individual projects (Hendry, Heinrich et al. 2005). 4) We also wanted to examine if student **performance** – high, intermediate or low performance (performance in the specific project or generally) could affect the learning outcomes (both positive and negative correlations have been found in earlier studies)(Conejo, Barros et al. 2013).

Based on these premises we formulated seven null hypothesis:

A0 Project **Engagement** is not correlated to exam results
B0 Project **Engagement** is not correlated to project results
C0 Project **Confidence** (a belief that the project will lead to higher learning outcomes) is not correlated to exam results
D0 Project **Confidence** is not correlated to project results
E0 Group work **preference is** not correlated to project results
F0 Group work **preference is** not correlated to exam results
G0 Exam **performance** is not correlated to project results

# 1 Methods

## *1.1 The course*

There were in total 86 engineering students active in the course, which were divided into 23 different project groups (3-6 students per group). The projects had different ecological focal research questions formulated by the coordinating teachers. The questions had an experimental (and if possible quantitative) approach. The different group projects were categorized in relation to three types of teaching environments: literature (meta analyses), data base observations/experiments/models (internet), and outdoor field experiments. In total there were 5-8 project groups per group work category.

## *1.2 Performance*

For performance measurement we used results from the written examination held at the end of the course. Overall this exam was a traditional written exam based on the contents of two course books (Skoog 2000, Gröndahl and Svanström 2011) and the lectures during the course. Although the last question in the exam was focused on the students abilities to use ecological theory in relation to their specific projects on the course, it was thus a group-specific question. We have used these two parts in the exam in this paper to correlate course theory knowledge (results from the written examination – credits for the group specific question excluded) with project work derived knowledge (the results from the group specific question).

## *1.3 Student evaluation survey*

We used a student online course evaluation and student results from individual and collaborative examinations and student's self-evaluation of learning outcomes to test our seven hypothesis. In the course evaluation we used a ten-graduated Likert-scale for measuring attitudes (Likert 1932), where 1 was set as "No I don't agree at all" and 10 was described as "Yes I agree completely". Values between 2 and 9 should be interpreted as gradually intermediate between 1 and 10 and were not described in words. Because of the need to relate student's results with their pedagogical surveys we chose a non-anonymous online course evaluation. The total response rate was 19 students out of 82 students participating in the course.

The statements used in the student online evaluation were the following:

| |
|---|
| 1. The project was very engaging and interesting. (Student **Engagement**) |
| 2. I learned a lot about ecology through project work. (Group work **confidence**) |
| 3. I prefer group projects rather than individual projects. (*Group work* ***preference***) |

## 2 Results

Overall the attitudes towards group work related activities in the course were relatively positive especially for the group work preference (average 7,8) but also concerning group work confidence (average 7,0) and student engagement (average 7,1). To test our hypotheses we used Spearman Rank correlation statistics. There was no correlation between student engagement and project result (Fig 1b), for student engagement there was a negative trend, although not significant (Fig 1a.).

Fig 1.

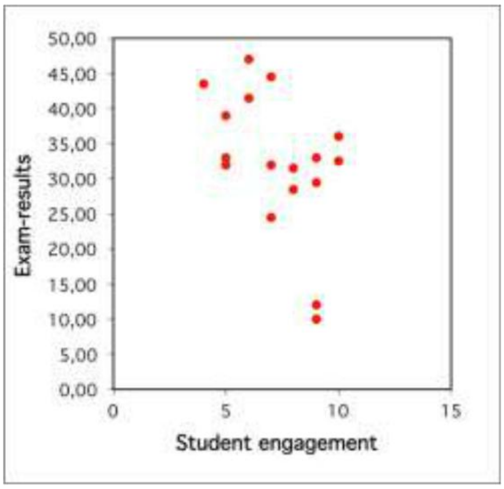



Fig 1a

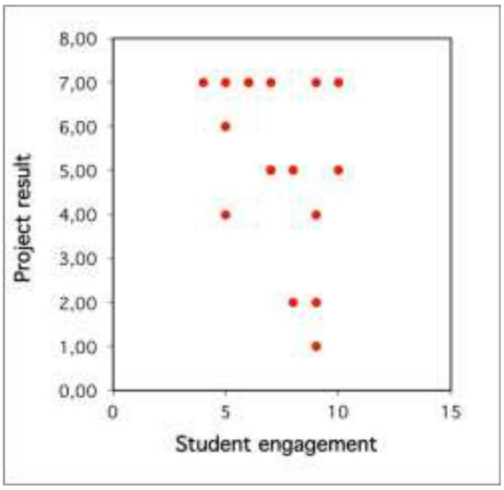
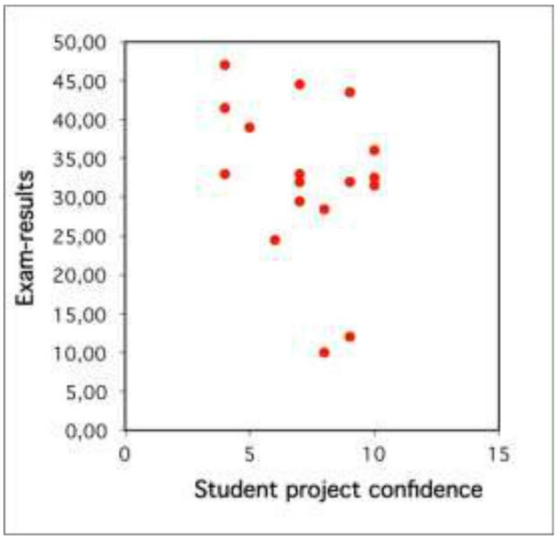



Fig 1b

Fig 1a-b. Figure 1 a shows a negative trend (Spearman R, -0,404, df =17, p = 0,0863), although insignificant between student engagement ("*The project was very engaging and interesting*." valued from 1-10 according to degree of agreement) and exam results (theoretical part of exam, project-part excluded). No correlation was found between project result and student engagement (Spearman R, -0,320, df =17, p = 0,1815).

Low-performing students on the exam tend to rank learning from the projects in the course higher compared to high performing students (Fig.2a) although there was no correlation between student project confidence and project result (Fig 2b).

Fig 2.



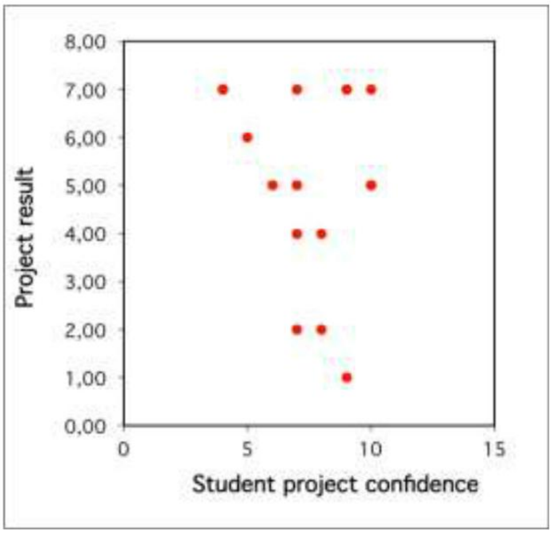
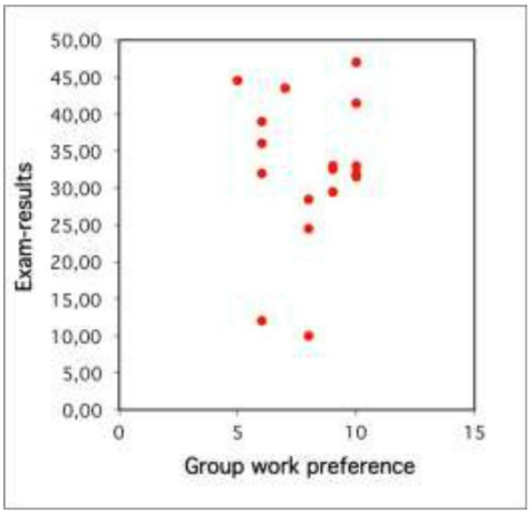




Fig. 2a Fig. 2b

Fig 2 a-b. There is a significant negative correlation (Spearman R, -0,473, df =17, p = 0,041), between exam-results and project learning attitude (*"I learned a lot about ecology through project work."*) while there was no correlation between project result and student project confidence (Spearman R, -0,212, df =17, p = 0,3825).

Group work preference was not correlated to either exam-results (Fig 3a) or project-results (Fig 3b). The exam results were not either correlated to project results (Fig 4).

Fig.3



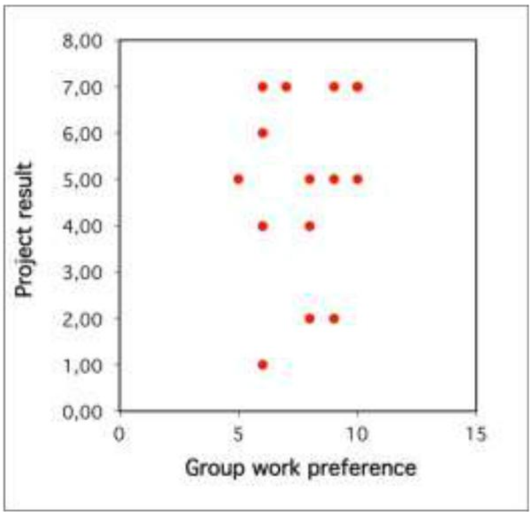




Fig 3a-b

Fig 3. No significant correlation as found either between exam-results and group work preference ("*I prefer group projects rather than individual projects.*"), (Spearman R, 0,252, df =17, p = 0,2985) or between project result and group work preference (-0,302, df =17, p = 0,2091).

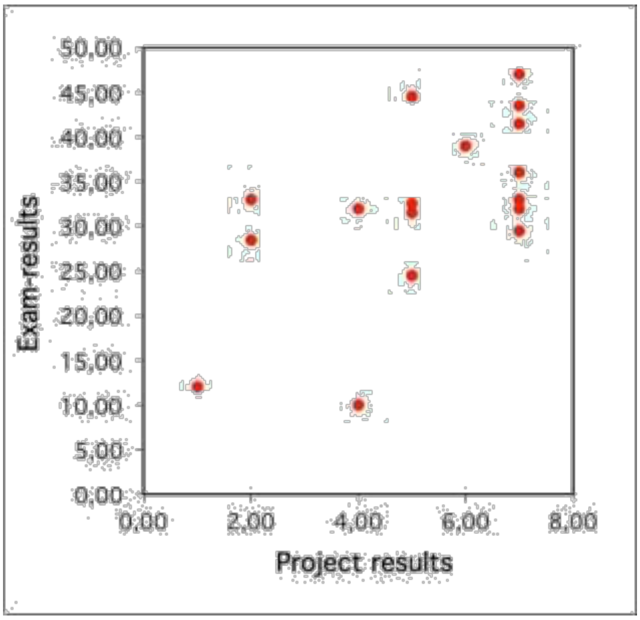



Fig 4. There was no correlation between exam results (theoretical part) and project results (project-related exam results), (Spearman R, -0,016, df =17, p = 0,9471)

A summary of the results in relation to the established hypotheses:

A0 - Project **Engagement** is not correlated to project results
*Not falsified*

B0 - Project **Engagement** is not correlated to exam results
*Not falsified but* a trend of negative correlation between the parameters were found

C0 - Project **Confidence** (a belief that the project will lead to higher learning outcomes) is not correlated to project results
Falsified, with a significant negative correlation between

D0 Project **Confidence** is not correlated to exam results
*Not falsified*

E0 Group work **preference is** not correlated to project results
*Not falsified*

F0 Group work **preference is** not correlated to exam results
*Not falsified*

G0 Exam **performance** is not correlated to project results
*Not falsified*

## 3 Discussion

Some of the basic principles in active learning approaches are the student-centred teaching and encouraging student engagement in the teaching process, resulting in higher motivation for studies. In collaborative learning the engagement is very much dependent on the type of collaborative work. The group work topic, working process and general structure should of course be interesting for the students (as well as for the teachers!) but needs also to be appropriate for learning at different individual levels. Individual student's learning should facilitate and not impinge other student's learning possibilities and/or hinder the overall group work process. This is often a juggling act, to manage to keep the balance between encouraging engagement (e.g. working with group work processes) and at the same time find the right knowledge level (zone of proximal development) for each and every student. Although engagement often is a basis for a well working collaborative environment, the group performance is also affected by for example the individual group members ambition, goal orientation, power of initiative, etc. (Lee, Kim et al. 2015).

The online evaluation in our study showed that students found the project work engaging (student engagement average 7,1 for student engagement with a maximum value of 10) and they generally believe in learning from the project work process during our course (project confidence had an average of 7,0 on a $10^{th}$ graded scale). The students performing well in the exam (high-performing students in this text) seemed to have lower confidence in the learning outcomes of collaborative work compared to low performing students (Fig 2a), and there was also a negative trend (although not significant) between student engagement and student exam performance (Fig 1a). This could be interpreted in several ways. Thinking in Vygotskian terms the zone of proximal development (Wass and Golding 2014) could in this collaborative work be estimated somewhere between the knowledge levels of high and low performing students in our course. In that case low performing students will reach new knowledge by scaffolding knowledge (Wass, Harland et al. 2011) during the project work from more experienced or capable student peers, while high performing students get new knowledge individually from other pedagogical approaches during the course (lectures, literature and the field visit) which will lead to a lower engagement and learning confidence of high performing students. This fact that no correlation between the exam results and project result (Fig. 4) could be found does not contradict this interpretation.

An alternative explanation for the negative confidence is the difference in learning ambitions between high- and low performing students(Lee, Kim et al. 2015). If the outcome of the collaborative work is poor an ambitious student will rank this as disappointing and would lean on other individual learning approaches for learning instead.

With these results as a basis it is somewhat surprising to find no correlation between exam results and group work preference (*I prefer group projects rather than individual projects.*) Generally, group work was also to a large extent preferred compared to individual projects. At least two different interpretations are possible here. Firstly high performing students might not have been challenged enough in the group work in this course (because of uninteresting topic, low engagement and or knowledge in fellow students or bad supervision), but are usually even more engaged and confident on the learning outcomes. A second alternative is that high-performing students still rank collaborative learning high in comparison to more individual projects (individual projects are more traditional and include less activities). In both cases, this underlines the importance of understanding scaffolding in collaborative work and how different performing students benefit from different learning processes.

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# From "I teach, hence they learn" to "we learn to learn"

## Reflections on a sustainability course for industrial bioscience engineering students in Ghent, Belgium

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### Abstract

It is acknowledged that for effective sustainable development, 'transitions' are required: vision guided changes in the cultures, structures and working fashions of societal systems. Drastic changes of such a transition-kind confront the myriad of societal actors with multiple elements of stress: being uncertain on success/outcomes, possibly leaving behind acquired achievements, potential reshuffling of power relations, orienting towards distant future horizons, etc. All these factors explain a 'normal' attitude of inertia and resistance, reinforced by multiple lock-in's in physical (infra)structures and mental models. In that light and being aware that sustainable development is essentially a matter of next generations' societies, some essential competences and skills would be welcomed; and should dedicatedly be developed and nursed throughout education. In this contribution we share the concepts behind an experimental course on 'sustainable production systems' (focussed on the agriculture and food domain) for industrial bioscience engineers at Ghent University (Belgium). Based on a vast 'we should'-body of literature, this course is built around six competences/skills that are considered essential for sustainable development and transition thinking and doing: understanding wickedness/complexity, systemic reasoning, envisioning and back casting, experimenting, (reflexive) monitoring, and collaborating/co-creating. The deployed 'teaching' approach is a flexible combination of activating teaching methods and interdisciplinary work formats; both calling for strong student participation. The applied 'flipped classroom' stream allows for maximum time availability for the practice of (inter)active learning; while making 'the theory' an easily available and out-of-class activity.

In this contribution, the deployed format is presented in more detail. However, the major messages refer to the actual learning experiences by both the teacher and the students that chose to take the course; the present paper is hence a joined co-creation endeavour. Not only the most essential considered 'content' aspects related to transitions for sustainable development are discussed. Also the process of 'learning to learn' will be object of the results and discussion: (how) did the specific approaches that were deployed in the course facilitate the process of recognising and appropriating essential transition competences/skills? And did we distinguish specific and/or generic assets of the approach that allowed experiencing additional/innovative/memory sticking elements of learning?

# 1 Introduction

## *1.1 Transition thinking for sustainability*

It is acknowledged that for effective sustainable development, processes of radical change are required: cultures, structures and working fashions of societal systems should profoundly be reconsidered (Frantzeskaki and De Haan, 2009) . Effective processes of such a 'transition' kind are envisaged to be robust enough to tackle the inherent complexity of the manifold of interwoven problem issues that underlie the sense of urgency for sustainability oriented endeavours (Grin et al., 2010; Loorbach, 2007). It is clear that such a transition-like attitude and practice is not common ground, in a world where problems are still preferably reduced to manageable, piecemeal and well isolated proportions. In that light, a number of currently underdeveloped assets and competences are considered quintessential for the necessary capabilities in service of effective sustainability transition progress and acceleration: long-term thinking, whole systems reasoning and innovation, involving multiple domains and actors, and an explicit focus on learning (Rotmans et al., 2001) and on critical thinking (Rieckmann, 2012). Being aware that actual outcomes of – even contemporary - sustainable development endeavors is essentially a matter of multiple next generations, these bare essentials deserve to be the subject of dedicated development and nurturing throughout education (Lozano et al., 2013; Lambrechts et al., 2013; Lans et al., 2014; Wals, 2014).

## *1.2 Transitions: systemic!*

The 'problem' issues that underlie the sense of urgency for sustainable development draw back on a multifold of sectors, activities, actors, organisations, scale levels, etc.; all of them interrelated in many ways and by diverse feedback mechanisms. The resulting inherent 'wickedness'(Rittel en Webber, 1973) of problem issues asks for more holistic analysis and solution approaches than the ones deployed by routine, contemporary practices of policy, of science, of industry, of civil society… and of education (e.g. Foley et al., 2011; Ferrer-Balas, D. et al., 2009; Gallopin, 2003; Senge, et al., 2008; Tukker et al., 2008). The typical incremental optimization modus builds on a comfortable division in well distinguished disciplines, sectors and departments, with their own logics, semantics and comfortable routines. Comparable with analogues for policy domains or industrial sectors, it may be clear that also educational programs are still predominantly following a logic of separate subjects and ditto subject courses, each comprising a discipline with an own systematic, language and a specific understanding of solving of relatively 'tame' problems. When it is acknowledged that actually whole 'systems' seem to fail, then more systemic understanding, reasoning and problem solving should be developed and practiced (Elzen et al., 2012; Ikerd, 1993; Spaargaren et al., 2012). Thereby, the indicated systems (innovation) approaches are not to be considered as a substitution of disciplinary knowledge and competences, but as a welcomed and respected competence with significant added value for professionals and citizens (Quendler et al., 2013). Moreover, genuinely systemic approaches go well beyond a disciplinary 'add-on' of sustainable development (e.g. Ceulemans and De Prins, 2010), which most often keeps emphasizing a merely ecological dimension (Watson et al., 2013). Considering the above, the theoretical framework of transition thinking has been mentioned before as a potentially suitable guiding framework for effective sustainability practice, also in higher education (Jansen, 2003, 2005; Stephens and Graham, 2010).

*"A welcomed variation on the pigeonholing…"*

*a student*

### *1.3 Transitions: vision guided!*

The envisaged drastic nature of changes needed for sustainable societies, and the inherent mission statement of sustainable development towards future generations, entail a long term future orientation as an essential element of transition thinking and practice. Uncovering a current system's functioning (systemic thinking, 1.2) informs on possible future scenarios (Shaw et al., 1992) and inspires the envisioning of desired, sustainable system configurations (Rotmans and Loorbach, 2009). However, long-term horizons typically lack from the practices of policy making, of economic decision making, and of scientific work. And even when long term thinking is included, in a majority of cases this is deployed in a predictive and/or explorative mode. Establishing normative principles of a desirable – sustainable- future and translating them in comprehensible narratives/images is far less common (Martinez et al., 2006; Nevens et al., 2008). Envisioning skills are underdeveloped; that kind of creative, pro-active potential is typically not encouraged nor 'taught' in educational programs (Meadows, 1996). Nevertheless, it should be acquired as a crucial discipline (Senge, 1990). In their evoking of shared orientation and guidance, envisioning capabilities and results are seen as a pathway to escape from the apparent paralysis of lock-in and inertia mechanisms (Quist, 2007).

### *1.4 Transitions: co-creation!*

Systems thinking as well as envisioning almost organically assemble a wide diversity of disciplines, actors, institutions and organisations involved. Such an inter- and transdisciplinary mode of operation may not be a routine one, but it is considered as highly required for co-creating sustainable future images and enrol aligned and effective initiatives (Kalaugher et al., 2013). Far going endeavours with regard to participatory practices of that co-creative kind and the coinciding 'governance' of transitions ask for specific attitudes and competences. Also in that specific domain, classic policy, science and industrial practices may not be well equipped . And also for education, a major task lays in developing willingness, consciousness and competences for inter- and transdisciplinary professionalism .

## 2 Methodology: a course on the experimental shovel

### *2.1 A course…*

At Ghent University, Master students in Applied Biosciences (a degree of the Faculty of Bioscience Engineering) can take the optional course of 'Sustainable Production Systems in Agriculture and Food'. The course is worth 3 ECTS-credits. It initially comprised six classroom seminars of 4 hours each (essentially ex cathedra teaching) and an estimated 48 hours of individual out-of-class assignment work. The evaluation combined, on a 50/50 basis, the results of a written exam on the seminar contents and of the compiled and presented individual student work. The major content issues of the classroom teaching sessions were a) generic unsustainability problems, b) major sustainable development approaches (such as eco-efficiency and circular economy), c) instruments for sustainability assessment (such as live cycle analysis and indicator tools) and d) specific sustainability approaches in agriculture (such as precision agriculture, integrated agriculture and organic agriculture). The typical classroom audience comprised 10 master students. From the 2015 spring edition on, the course was taken care of by a new assistant doctor (the author of this paper). In spring 2016, that same instructor launched the course in a revised format, based on accumulated insights of 15 years of research on sustainable development in agriculture and other sectors. Inspired by 'transitions' for sustainability (see 1.1), the new course version was established and launched as an experiment, for which it was also recognised and financially supported by the Faculty Commission on Educational Innovation.

### 2.2 … on the shovel.

The spring 2016 version of 'Sustainable Production Systems in Agriculture and Food' kept the same amount of available time for classroom activities and for autonomous work; as well as the same ECTS credits. Yet, the format and content of the course were drastically changed. It was designed under a tentative label of 'Flipped Active Classroom', referring to the incorporated approaches of flipped classroom (O'Flaherty and Philips, 2015) and of activating teaching methods (Meyers and Jones, 1993).

The different content elements that were considered were a) diversity and interrelatedness of unsustainability issues, wickedness/complexity of problems, b) systems analysis and systemic reasoning, c) long-term envisioning, d) sustainability niches and experiments, e) sustainability transitions and their governance, f) sustainable development evaluation and monitoring. By handling these more 'conceptual topics', the idea to deliver a clear-cut 'recipe book' of fully fledged sustainable practices (comfortable in an engineering context with a typical technological focus) was explicitly renounced from. Previous experiences and insights of the responsible teacher inspired an approach in which a coherent ensemble of the mentioned elements has high potential to contribute to the envisaged competences for sustainable development (see 1.1).

Flipped classroom: for each of the above mentioned content elements, online video clips from annotated power points slideshows, were posted as protected movies on YouTube (in a kind of 'massive open online course' philosophy; Leire et al., 2016). Students were asked to watch the movies as preparation of the actual classroom seminars. The movies showed the very essentials of the underlying theory/concepts; the average duration of about 20 minutes urged the teacher to make a careful selection of the very core material. During the contact 'classroom' sessions, besides some explanatory questions, no further explicit attentions was paid to the theory in the movies. In fact, the contact hours were fully used to actually deploy, apply, discuss and feel the meaning of the conceptual matters. To invoke this pronounced experiential aspect, a number of activating methods were deployed.

Active classroom: almost the entire contact time in each of the seminars was spent on interactive endeavours: causal loop diagram construction and discussion, future envisioning by collage of images and drawings, brainstorming, individual experiment design by use of business model canvas, peer evaluation, on-the-field interview and even an actual field work session at a CSA (Community Supported Agriculture) initiative. This active learning pedagogical approach was described before to increase students' knowledge on sustainable development (Segalàs et al., 2010) and to enhance complexity related competences (Yakovleva and Yakovlev, 2014); the flipped classroom format was meant to create the necessary time for this activation.

### 2.3 Learning by doing

The foregoing description of the course 'as intended' was actually implemented in Spring 2016, that is to a large degree: while ongoing, some elements were skipped or left out, others were added. This will be further discussed below, but is mentioned here because it illustrates the genuinely experimental upset and an attitude of adaptability/flexibility. The experimental approach was in itself considered as an actual practice of transition: in that conceptual sustainability approach, experimenting is indicated as a crucial asset/activity. The students were fully informed of the experimental onset of the course and by doing so, they were already aware that the course itself (with them as participants in it) could be considered as a real life element of sustainability transition practice. In hindsight, the transparent experimental mind-set of the course enabled an attitude of creativity 'while ongoing', both from students and teacher. During the course of the course, reflexive moments were included in the actual sessions; an additional feedback/evaluation from the students was requested after the last seminar. In general, we jointly followed the acknowledgment that learning is an open ended system and that all of us -students and teachers- should be considered as learners (Budwig, 2015).

In what follows, we present a selection of findings/learnings that we consider relevant. We do not have any intention of contributing to any high range and rectifiable theory, or to hold silver bullet guidelines/advices. Rather, and in line with what 'transition experiments' are all about, we want to build on some explicit reflexion in relation to what the course actually realised; and share findings and experiences which might be interesting in other contexts of kind-like endeavours or quests.

In that, we acknowledge the overall critique on case study research in that it will always be partial and situated and hence might not answer potential request for systematics (Hargreaves et al. 2013; Scoones et al. 2007; Yin 2009). Yet, also that aspect fits in transition-inspired sustainability practice, embracing tailor-made realisations accompanied by shared learning. Learning-by-doing, doing-by-learning.

## 3 Outcomes and discussion

### *3.1 The 'plan' versus the 'realised': flexibility with a systemic overview*

The initial schedule of six content elements to be treated was not strictly realised. In fact, the foreseen seminars on sustainable transition governance and on sustainable development evaluation/monitoring were not implemented. Besides some initial practical troubles with the movie clips, one of the reasons for that was that foregoing sessions/topics – since 'not finished' - extended in a next seminar meeting; and hence the available time had ran out for explicit individual treatment of the last two topics. However, while ongoing, it became clear that when initially thinking in 'individual' elements that would gradually emerge into a coherent whole, a more rapid dynamic seemed to develop. By the interactive practices, other –'subsequent'- elements quite organically and rapidly also came into earlier debates and interactions. This was not only seen as a confirmation of the rational and logic coherence of the considered elements, but also an indication that the envisaged target of systemic thinking and reasoning might quite soon have been taken off. The gradual systemic 'synthesis' (Kay and Foster, 1999) and very much wanted holistic perspectives (Lozano, 2010) can apparently rather organically emerge by a good interaction/co-creation of all the learners. An important precondition for ignoring the initial reflex of 'out of scheme' and/or 'loss of time' is the awareness that a number of issues-to-come are already being interwoven in early steps. This insight asks for an underpinned systemic (!) overview of the guiding teacher into the different elements, their coherence and the semantics and concrete issues that are being brought in. After all, appropriate systems thinking interventions (or the deliberate absence of them) are inspired by recognising interconnections and identifying feedback (Hopper and Stave, 2008), also in teaching on systemic issues such sustainability transitions. Not strictly adhering to 'the plan' and hence leaving room for emergence, adoption, serendipity, creativity, etc. is also an illustration of what is expected from practitioners in real life sustainability transition processes. And in that, knowing that it was considered as an experiment, the course itself was exemplary to that very asset that was also meant to be 'taught'. Making explicit the meaning of such happening to the students is essential to evoke the desired learning; and to make it sticky, by the actual experience of being part of it. Experiential learning is known to be an effective model for education on sustainable development (Dieleman and Huisingh, 2006), and besides by 'excursion examples', this can also be incorporated in the way a 'course' is practised. Again, there is the impression that this asks for a degree of mastery and recognition of transition process essentials.

### *3.2 Tell me, show me, involve me: we co-create!*

The general idea behind flipping and activating the classroom was to minimise theoretical tell-me-education, and maximise actual involvement of students. In accordance with other reported experiences (e.g. Smithikrai, 2016), working with online movie clips and thereby maximising interaction time in class was welcomed. In hindsight, when having observed what students seemed to be capable of (based on the engagements in the interactive seminars and the end presentations), it is clear that extended and deep knowledge of e.g. complexity theory is not that essential for effectively being able to think in systemic terms and/or find solutions that go beyond a classic 'own turf'. In that, the minimisation of explicitly theoretical explanations, allowed for much time for interaction based on practical aspects and readily available knowledge/information within the students own 'library'. Interactivity makes the understanding of fundamental concepts more easy (Ceresia, 2016); and aided by concrete issues brought up by students themselves allowed the teacher to tag concrete items with the theoretical or conceptual ideas they fit (typical examples are circular, peer-to-peer, sharing economy, eco-efficiency,…). In that, and as a teacher, one no longer actually hands over knowledge, but one enables students to position/frame what they already know, in broader contexts of sustainable development/systemic settings. Additionally, much of the telling is done by the students themselves: they bring up a variety of examples and experiences that enrich the group's perspectives as well as their individual rucksack of knowledge and awareness. 'Involvement' in the course was also encouraged by giving students the opportunity of suggesting what might be useful activities to deploy during the seminars to come; in doing so, they experienced that even in an environment in which they anticipate/expect that things are decided, organised and planned for them, there can be opportunity to co-create alternative pathways or initiatives that are desired. Even in their own school/university system, experimentation and co-creation can take place (like it should be made possible in other societal settings, according to transition thinking). The example of that was the own suggestion, organisation and guidance of the field visit to a Community Supported Agriculture farm. This visit not only resulted in an informing interview about alternatives for the dominant agricultural system. It also proved to a good example of experience economy, of exchange economy and of alternative value exchange devices: in return for the interview and visit, the students and teacher worked at the farm for 1,5 hour, the equivalent of one working day for the host farmer.

In general, the interactive setting and the gradually installed atmosphere of trust in expressing individual ideas, of constructively criticising other viewpoints, and of respecting diverging opinions at least illustrated the usefulness of critical (group) reflection; certainly by engineering students and about the values and assumptions that typically inform engineering practices (Carew and Mitchell, 2008). Confirming Segalàs et al. (2010), social and institutional aspects organically got paramount attention; and reflexive and relational (re)consideration about the multiple impacts of decisions was triggered when allowing multiple perspectives (Roos, 2015). A drawback aspect of the course, highlighted by the students, was the actual lack of contacts/interaction with students from (completely) different disciplines such as sociology, politics, psychology, etc. 'Co-creation' was –validly-conceptualised as going even far beyond the experienced modest onset in the present group of still dominantly likeminded.

*"The self-paced learning of the theory makes you study even before the actual lesson"*

*a student*

### *3.3 There's learning and there's learning: **we** learned*

Based on feedback from the students, and on the foregoing reflection on outcomes, a general idea is that students actually learned in a number of ways and in accordance with a number of the envisaged much wanted transition/sustainable development competences and skills, such as systemic reasoning. Part of this learning was inspired or guided by the instructor. However, an important enabler of learning was the (autonomous) interaction between the students: they learned via 'participant turnover', that is from each other's examples, experiences, opinions, reflections. As such they additionally learn as a group (Brown and Vergragt, 2008). In that, they again experienced an important feature of transition practices: combining diverse opinions, addressing multiple sources of knowledge and connecting multiple potentials of expertise is an major lever for genuinely innovative and effective action for sustainability.

From the instructor's point of view, multiple elements of learning became clear (and probably still more will become clear): recognise those elements that are already present within the students and recognise emergence of elements and events that perfectly fit the intended learnings and/or allow for contextualisation. In the end, an own 'teacher transition' from translator of information towards organiser and coordinator of an educational process, might be the most appropriate synthesis for the major lesson learnt with regard to the challenging mission of 'forming' complex competences (Yakovleva and Yakovlev, 2014).

*"Standing and walking around during the lessons… can't be bad and it is sustainable as such!"*

*a student*

3.4. Some limitations…

The sketched experiment also revealed a number of drawbacks and limitations. A first one is that the interactive approach doesn't allow for application in large groups of students. It is estimated that a maximum of approx.15 students permit effective interaction. At the same time, it is to be expected that not every student has the same capacity, interest and inclination for the very kind of activities (although the discovery of the specific value can be a very learning effect) and hence not a 'whole population' should be envisaged as target audience. A concurring challenge then is to reach out to the non-audience with transition essentials in the 'regular' courses of the specific curriculum (other ongoing work…). Secondly, some students à priori expressed an expectation that is rather in line with recipe-like practical solutions for sustainable development and were consequently slightly disappointed in that very aspect (although acknowledging the added value of the experienced more holistic and less prescriptive approach).

*"Little technical and scientific solutions were treated… but then I'm better with facts and numbers…"*

*a student*

## 4. A generic conclusion

To conclude on perhaps the most meta-level of reflection: the sketched experiment and the present 'report' on it, embody that we should reflect more on how we learn, as students, as teachers, as practitioners, as a little of all three (Holden et al., 2008); and that probably the clearest way to ensure transformative learning for effective sustainable development competences is for instructors to be transformative learners themselves (Cranton, 1994).

*"I didn't know that this kind of teaching/learning was possible…"*

*a student*

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# Green Power Generation: Computer Aided Design & Life Cycle Analysis (LCA) of Wind Turbine

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## Abstract

Wind turbine design has been presented as a source of green power generation through solid modeling. The components of wind turbine have been designed and created through CAD software. Then each component has been tested for its strength through finite element analysis (FEA). Life cycle analysis and life cost analysis have been performed on the entire wind turbine including embodied energy analysis, turbine manufacturing and dismantling have been presented. Embodied energy of wind farm operation to maintenance has been presented. From total cost, the proportionate cost for different categories like administration, insurance etc. are shown in life cycle cost analysis.

## 1 Introduction

Scientific opinion on climate change has reached a new level of concern. The Intergovernmental Panel on Climate Change (IPCC) has concluded that Earth's climate will change, though it may not be agreed by when and by how much. Global mean surface temperature has increased in the range of 0.3 – 0.6° C since the 19th century. In addition, global sea levels have risen by 10-25 cm during the same period; much of which may be related to the temperature increase. According to IPCC, these changes are "unlikely to entirely natural in origin". The balance of evidence suggests an identifiable human influence on global climate. Global warming is mostly credited to greenhouse gases, which allows solar radiation to penetrate the atmosphere, and absorbs the infrared radiation reflected back by the Earth's surface. These infrared radiations trapped in atmosphere causes the air temperature to rise. During the industrial revolution and after that greenhouse gases from human sources (anthropogenic) have been accelerating, in proportion to the growing use of fossil fuels. Carbon dioxide ($CO_2$) is the most polluting gas and subsequent global warming, followed by methane ($CH_4$) and nitrous oxide ($N_2O$). The concentration of $CO_2$ in the atmosphere has gone up by 28% during the last 1000 years. It is estimated that global temperature will rise by 1-3.5° C, and sea level rise by 15-95 cm by the year 2100. The United States is the world's largest greenhouse gas contributor, accounting for 25% of global emissions. The vast majority of greenhouse gas emissions in US in the result of energy consumption of which electricity comprises a significant proportion. It is estimated that 40% of U.S. $CO_2$ emissions were due to combustion of fossil fuels by electric utilities. Therefore, it is obvious that generation of electricity should be diverted to renewable sources as far as possible or green power generation.

### *1.1 Greenhouse Gas Emission Rates:*

The energy requirements for each phase of the life-cycle can be used to estimate the greenhouse emissions. This methodology provides a better estimate of greenhouse gas impact than simply estimating plant emissions for various green power generation technologies. Carbon dioxide is a byproduct of fossil fuel combustion. Because the vast majority of U.S. energy is produced by using fossil fuels, each energy input within the life-cycle has corresponding $CO_2$ emissions. Carbon dioxide is the most significant greenhouse gas based on total global emissions. Methane ($CH_4$) and Nitrous oxide ($N_2O$) are actually stronger warming agents, but have far lower global emission rates. When averaged over 100 years, $CH_4$ has a 21 times stronger global warming potential than $CO_2$, meaning 1 ton of $CH_4$ emissions can be equated to 21 tons of $CO_2$-equivalent emissions. $N_2O$ has a 310 times stronger global warming potential than $CO_2$.

## 2. Wind Power Generation

Wind energy is green energy because during the generation of power, the environment is not polluted. Wind energy is renewable energy simply because the 'fuel' used to generate electricity, i.e. the wind, is practically unlimited. There is significant variation in wind turbine size depending on purpose. Smaller turbines are generally used to power a single household and have a capacity under 100 kilowatts – most commonly around 2 kilowatts. Commercially sized turbines have a capacity of up to 8 million watts. In order to convert wind energy into electricity, an average wind speed of 14 mph is required. Wind turbine blade length and height are the main differences between commercial and residential turbines. Residential turbines generally stand at around 10 meters tall, while commercial turbines are anywhere from 30 to 100 meters tall.
Wind turbines or wind generators are used to convert the natural kinetic energy produced by the wind into useful mechanical energy. The central purpose of the wind turbine is to turn the generator located within the main housing just behind the three large blades; this main housing is called the nacelle. The generator will then take the mechanical energy and create electrical power. The power is transmitted within the nacelle through a series of shafts connected by a gear box. The lower speed shaft is connected to the rotor which holds the three large blades as seen in Figure 1. As mentioned above, a wind turbine consists of 4 main parts. They are the rotor, nacelle, tower, and the foundation. The complete design and finite element analysis of all main mechanical components is presented. The rotor blades intersect the wind and capture the energy it contains, which causes them to rotate in a vertical plane about the shaft axis. The slow rotation of the shaft is normally increased by use of a gearbox, by which the rotational motion is delivered to a generator. The electrical output from the generator is then transferred through cables and down the turbine tower to a substation where the power is eventually fed into the electricity grid. The mechanical components housed at the top of the turbine tower- the rotor, gearbox, and generator – are all mounted in the nacelle that can pivot, or yaw, about the vertical axis, so that the rotor shaft is always aligned with the wind direction.

Components of a Wind Turbine System are shown in the Figure 1. The specialized shape of the blades is what allows the movement of the entire system. Certain points along the cross-section of the blades are shaped like an airfoil, and like with the cross-section of an airplane wing, this shape creates a force perpendicular to the length of the blade or tangential to the swept area of the blades. Figure 3 shows the shape and forces involved with the blades.

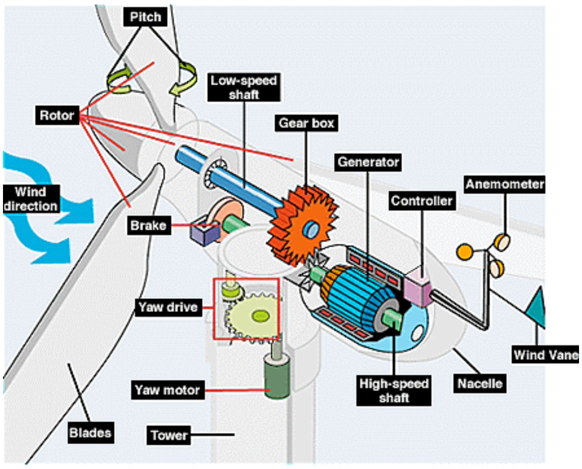



Figure 1: Wind Turbine System (U.S. Dept. of Energy)

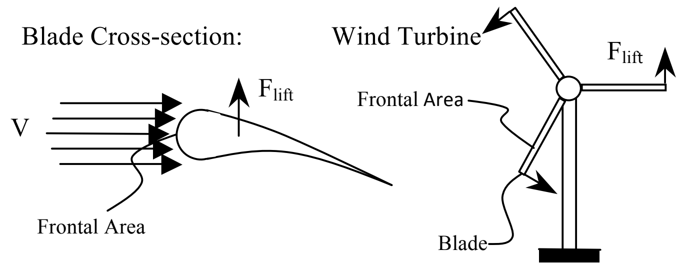



Figure 2: A Typical Wind Turbine

Figure 3: Blade Design

Most wind turbines can produce a velocity tangential to the swept area at the blade tip ($V_t$) of between 40-60m/s, giving the low speed shaft an angular velocity of only 4-6 radians per second (40-60 rpm) for a 21m diameter swept area. The generator however requires much faster speeds to produce electric power, therefore the low speed shaft is equipped with a large gear with many teeth and then that gear is in contact with a much smaller pinion gear that is then attached to the high speed shaft which is in direct connection with the generator. The effect of the gear box is that the high speed shaft will move at a higher velocity directly proportional to the number of teeth of the larger gear over the number of teeth of the smaller gear. The gear box in Figure 1 has a ratio of only 1:5 which is low for typical turbines which have ratios between 1:25 and 1:50. Low speed generators do exist; however, they are very expensive. The gear teeth carry loads proportional to their respective torque over the gear radius. The teeth must be made strong enough to endure repeated stresses. The base of the turbine, called the tower, is a long and hollow cylindrical piece which acts as a column to support the blades and nacelle. The tower must be designed to avoid buckling under the weight on top of it and to avoid bending possibly produced by the wind forces hitting the front of the wind turbine. The wind also creates stresses in the blades due to bending moment. The dynamic stresses are all due to the turning of the blades and both shafts. The shafts must be sized appropriately to avoid deformation due to torque. Making wind turbines a more significant source of energy in the future depends on the arrival of better and lower cost materials which can be produced in high volumes and still be reliable. There is trend towards lighter weight materials but sophisticated materials are often too expensive to justify using. The turbine tower can represent up to 65% of the weight of the entire turbine. Low cost materials such as reinforced concrete are now being used for the tower.

## 3. Mechanical Components Design:

Most component design parameters are adapted from (Budynas *et al.*, 2008) and (Tester *et al.*, 2005). Siemens NX is used for both CAD and FEA to assess the strength of the turbine components. The full wind turbine has not been assessed in FEA, only components are evaluated separately. No code standard has been used to perform the FEA assessment. The components evaluated in FEA include: tower, blade, and nacelle. The first component to be analyzed is the tower which, as mentioned before, makes up most of the entire weight. The tower has to support the weight of the nacelle and blades which for most wind turbines is approximately 73 tons (716 kN). Assuming a 50m tower made of steel which is fixed at the base, the Euler column formula (Eqn. 1) shows that the second moment of area would have to equal:

$$F_{cr} = \frac{C\pi^2 EI}{L^2} \Rightarrow I = \frac{F_{cr}L^2}{C\pi^2 E} = \frac{(716000\text{N})(50\text{m})^2}{\frac{1}{4}\pi^2(190\times10^9\,\text{Pa})} = 0.0038\text{m}^4 \quad (1) \qquad I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) = \frac{\pi}{64}\left(2.2^4 - 2^4\right)\text{m}^4 = 0.365\text{m}^4 \quad (2)$$

A simple hollow cylinder was created in NX-9 by first drawing two circles with the same center point in the same plane. The larger and smaller circles were made 2200mm and 2000mm respectively and extruded together 50m. Figure 4 shows the tower model.

FEA was performed in NX-9 to test the tower for buckling. The results showed a buckling load factor of 225 as shown in Figure 5 at right. Tower may bend due to strong winds creating a pressure over the entire frontal area of the turbine. The frontal area would be approximately equal to the 3 blades, nacelle, and tower added together. The combined force on the turbine is shown below using a wind speed of 15m/s at sea level:

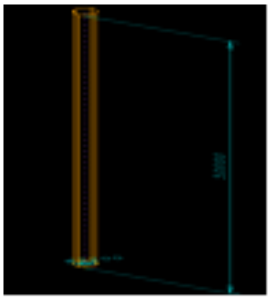


Figure 4: Tower Model

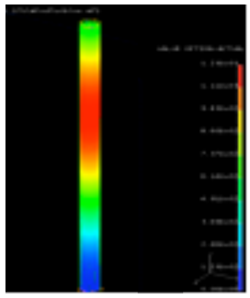


Figure 5: FEA of Tower

$$A_{blade} = rd = (7.125\text{m})(1\text{m}) = 7.125\text{m}^2 \tag{3}$$

$$A_{turbine} = 3A_{blade} + A_{tower} + A_{nacelle} = 3(7.125m^2) + (30m)(2.2m) + \pi(2.3m)^2 = 107m^2 \tag{4}$$

$$F_m = \rho_{air} V_{\max}^2 A_{turbine} = \left(1.23\frac{\text{kg}}{\text{m}^3}\right)\left(15\frac{\text{m}}{\text{s}}\right)^2 (104\text{m}^2) = 28.78\text{kN} \tag{5}$$

The material chosen is SAE 1006 hot rolled steel with yield strength of 170 MPa. The bending stress is calculated below shows very high factor of safety.

$$\sigma = \frac{Mc}{I} = \frac{FLc}{\frac{\pi(d_o^4 - d_i^4)}{64}} = \frac{(28.88*10^4\text{ N})(30\text{m})(1.1\text{m})}{0.365\text{m}^4} = 23.03\text{MPa} \tag{6}$$

Side View: F

c

L

Possible Cross Sections:

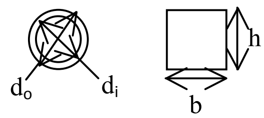



Figure 5: Beam

Three blades have been found to be the most efficient when considering aerodynamic efficiency and cost. Aerodynamic efficiency increases six percent from one to two blades and three percent from two to three blades and then less after that. Selecting a blade length is directly related to the desired power output of the wind turbine. A certain amount of power is available in the wind depending on its speed and density. The wind turbine can capture that power but the actual power output is reduced by the turbine efficiency, generally about 35%. Therefore the power required from the wind for a 10hp output is equivalent to 7.45 kW. The wind power is shown Eqn. 7.

$$P_{wind} = \text{Real Power / Turbine Efficiency} = \frac{7.45\text{kW}}{.35} = 21.286kW \tag{7}$$

The radius of swept area which is approximately blade length is calculated below.

$$P_{wind} = \frac{1}{2}\rho_{air} A_{swept} V_{wind}^3 \quad , \quad \text{where } A_{swept} = r^2\pi \quad , \quad \text{and r} = 7.142\text{m}$$

A blade was created by drawing five different cross-sections, four of which are airfoils and one circle, initially in the same plane (MIT, 2011). Each cross-section was then moved in the z-direction in increments that would add up to 7.25m. Figure 6 shows the blade cross-sections from two views:

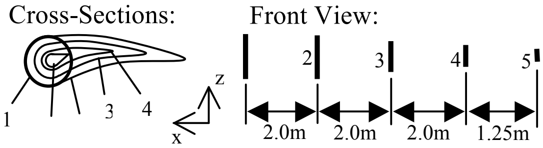



Figure 6: Blade Design Detail

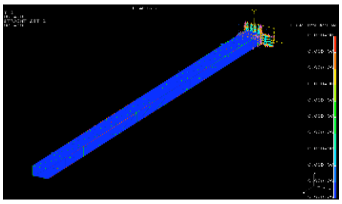


Figure 7: FE Blade Analysis

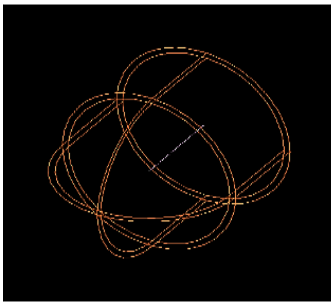


Figure 8: Rotor Solid Model

The blade was approximated by a square cross-section. The force and normal stress associated with the wind and blade can be seen below:

$F_{blade} = 3.506\text{kN}$ , bending stress was calculated as $\sigma = 1.6\text{MPa}$

An FE analysis was also modeled in NX and showed no major structural concerns as shown in Figure 7.

Figure 8 shows the completed solid model of the rotor. The round shaped creates an ideal aerodynamic shape to minimize drag. The nacelle was created in a similar fashion as the blade in that two circular cross-sections were created and then lofted together. This shape, like the rotor, is aerodynamically effective.

Wind turbine blades generally move with a tangential velocity at the ends ($V_t$) of 50m/s. Higher values are used to make gears and pinion. Using this value an angular velocity ($\omega$) can be obtained for the low speed shaft and then a torque based on the power expected from the wind. The force on a tooth on the first gear is shown in Figure 9.

$W_t = 33.16\text{N}$ and stress on the gear tooth is calculated as $\sigma = 77.7\text{Pa}$

An FE analysis of the gear tooth is safe as shown below:

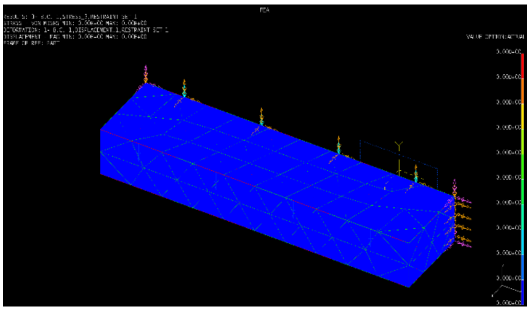


Figure 9: FE Analysis Gear

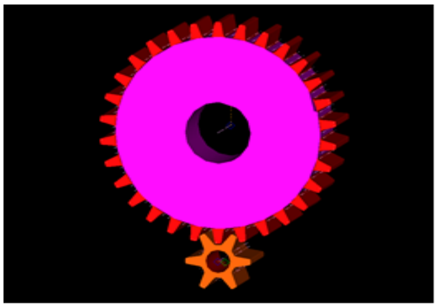


Figure 10: Solid Model Gears

Table 1: Percentage of Materials for Large Turbines (Kutz, 2007)
*Glass Reinforced Plastic, **Carbon Filament Reinforced Plastic

| Component /Materials | Permanent Magnetic | Concrete | Steel | Al | Cu | GRP* | Wood Epoxy | CFRP** |
|---|---|---|---|---|---|---|---|---|
| Rotor | | | | | | | | |
| Hub | | | (95)-100 | (5) | | | | |
| Blades | | | 5 | | | 95 | (95) | (95) |
| Nacelle | (17) | | (65)-80 | 3-4 | 14 | 1-(2) | | |
| Gearbox | | | 98-(100) | 2 | 2 | | | |
| Generator | (50) | | (20)-65 | | (30)-35 | | | |
| Frame, Machinery and Shell | | | 85-(74) | 9-(50) | 4-(12) | 3-(5) | | |
| Tower | | 2 | 98 | (2) | | | | |

## 4. Life Cycle Analysis of Wind Turbine:

### *4.1 Embodied Energy Analysis of Wind Power Generation*:

The life cycle of a wind farm consists of turbine production; turbine transportation to the site; site construction (which includes wind farm fixed assets); wind farm operation and maintenance; and dismantling, scrapping, and land reclamation. The various phases of the life cycle with energy inputs and electrical energy output (Jha, 2016), which is the only useful product, are illustrated in Figure 11 below. A sample of data is presented below in Table 2 for lifecycle analysis.

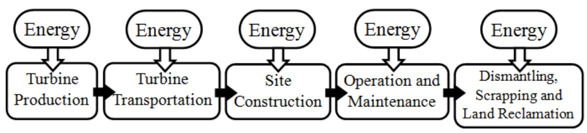
Table 2 shows the operational characteristics and the estimated lifecycle electrical energy output of the Wind Power Generation system presented earlier. The useful life has been assumed to be 20 years and with an availability factor of 90%, a full power lifetime of 18 years is calculated. Normally, the turbine only operates when wind speeds are in the range 4-25 m/s. Within this range it is assumed the turbine can only generate electricity at full generation capacity at a nominal speed of 15 m/s. The full power life of the wind farm is calculated as 20x0.90=18 yrs. The net power output of the wind farm is calculated by multiplying the capacity of wind farm by annual load factor.

Table 2: Useful Wind Farm Energy Data

| Description | Amount |
|---|---|
| Wind Power Capacity | 10 hp (7.45 k W) |
| Lifetime | 20 years |
| Availability Factor | 90% |
| Annual Load Factor (Turbine efficiency) | 35% |
| Full Power Lifetime | 18 |
| Net Power Output | 33556.5 W |
| Lifetime Net Power Output | 604017 W |

The lifecycle electrical energy output of 604017 W was calculated by multiplying the full power life time by net power output.

Figure 11: Lifecycle Energy Flow of a Wind Farm




### *4.2 Turbine Manufacturing and Dismantling:*

The embodied energy of turbine manufacturing and dismantling is calculated as shown below. Tower, shaft, and gears are made of steel. The volume of the steel used in the turbine manufacture is shown below:

*Steel:* Nacelle Volume= $\pi/4*4.6^2*15$=249.3m$^3$

Frame Volume: The length of complete frame and shell over generator, gearbox, and cone is assumed to be 3 times the length of slow speed shaft. The slow speed shaft is of 6000 mm and hence the frame length is about 6000mm. There is likely to be of oval shape and it is assumed that largest diameter of 1000mm (twice the size of the main gear). The volume of material of the frame and shell is presented at right.

$$V_{tower} = \frac{\pi\left(2.2^2 - 2^2\right)m^2}{4} \times 30\text{m} = 19\text{m}^3$$

$$V_{gears} = \left(\frac{\pi(2.9)^2}{4} + \frac{\pi(0.425)^2}{4}\right)\text{m}^2 \times 0.8\text{m} = 5.4\text{m}^3$$

$$V_{shaf\ ts} = 5.2\text{m}\left(\frac{\pi(0.3)^2}{4}\right)\text{m}^2 + 7.2\text{m}\left(\frac{\pi(0.8)^2}{4}\right)\text{m}^2 = 4\text{m}^3$$

*Steel:* Frame volume = π / 4x1$^2$x6 =18.846 m$^3$, Total steel in turbine = (19+5.4+4) m$^3$ x 7860kg/m$^3$=334x10$^6$g=223 ton

*Glass Fiber:* Volume of Blade =7.125x3=21.375m$^3$, Blade mass =21.375m$^3$x2440kg/m$^3$=52 ton

*Aluminum:* From Table 1, Aluminum is used in Hub-2%, Nacelle-4%, Gearbox-2%, Frames & Shells-50%, and Tower-2%. The mass of Al estimated:

Al=.02x33m$^3$+.04x249.3+.02x5.4+.5x18.846+.02x33 =718.9m$^3$, mass of Al=116 tons

*Copper:* Volume =.14x249.3+0.02x9.4+0.35x100 (volume of generator assumed) +0.17x18.846=73.3m$^3$, Total mass of copper used=73.3x8940 kg/m$^3$=65 ton

Permanent Magnetic material materials are used in Generator=50% and Nacelle=17%.

The volume of magnetic materials used in Wind Turbine; Magnetic material volume=.17x249.3+.5x100=42.931m$^3$, mass of permanent magnet=7.7g/cm$^3$x42.931=322ton

(Density of the Permanent Magnet is taken from Hunghon Dunben Magnetic Co. Ltd, China website)

Table 3: Embodied Energy of Wind Turbine Construction Material

| Material | Mass (Ton) | Energy Intensity (GJ/ton)+ | Embodied Energy (GJ) | Percentage of Total (%) |
|---|---|---|---|---|
| Aluminum | 116 | 200 -240 | 2.32x10$^4$-2.784x10$^4$ | 52-53.4 |
| Copper | 65 | 68-74 | 4.42x10$^3$-4.81x10$^3$ | 9.2-9.9* |
| Steel | 223 | 29-35 | 6.467x10$^3$-7.805x10$^3$ | 14.5-15.0 |
| Glass Fiber | 52 | 23.8-26.3 | 1.238x10$^3$-1.368x10$^3$ | 2.8-2.6* |
| Perm. Mag. | 332 | 28-31 | 9.296x10$^3$-1.029x10$^4$ | 19.7-20.8* |
| | | Total Embodied Energy | 4.462x10$^4$-5.211x10$^4$ | |

*It is noticed that increase in the embodied energy does not increase the percentage increase.

+ Energy intensity data is taken from (Ashby, 2009).

In addition to the embodied energy calculated above in Table 3, the embodied energy in production of turbine along with its transportation to the wind farm site should also be calculated. This data was not readily available.

This analysis is for a 7.45kW turbine. Larger turbines will have proportionately larger embodied energy.

### *4.3 Site Preparation and Construction:*

The embodied energy of site preparation and construction includes site construction building materials, non-material related site preparation, construction processes, fixed assets, and equipment (excluding wind turbine). The site construction building materials include the wind turbine foundations, cable trenches and cables, paths and roads, and site office. The results are presented below in Table 4.

Table 4: Embodied Energy of Site Preparation and Construction

| Description (Construction Materials) | Materials (Ton) | Embodied Energy (GJ/Ton) | Embodied Energy (GJ) | Percentage (%) |
|---|---|---|---|---|
| Turbine Foundation (Steel, Concrete)* | Concrete – 720 | 1.1 – 1.2 | 792 – 864 | 30.2 – 32.7 |
| | Steel – 30 | 29 – 35 (Low C) | 870 – 1050 | 35.9 – 36.7 |

| | | | | |
|---|---|---|---|---|
| Cable Trenches and Cable** | Corrosion Resistant Steel – 0.136 | 32 – 38 (Low Alloy) | 4.352 – 5.168 | 0.01797 – 0.01806 |
| Paths and Road*** | Soil – 50 | 2.2 – 2.3 | 110 – 115 | 4.0 – 4.5 |
| | Stone – 100 | 4.9 – 6.4 | 490 – 640 | 20.2 – 22.4 |
| Site Office | Concrete – 10 | 1.1 – 1.2 | 11 – 12 | 0.4194 – 0.4542 |
| | Steel – 5 | 29 - 35 | 145 – 175 | 6.0 – 6.1 |
| Total Embodied Energy | | | 2422 – 2861 | |

* The amount of concrete in foundation of a turbine is 300 $m^3$. It was assumed it has a density of 2400kg/$m^3$. Hence the mass of concrete for each foundation is calculated as 720 tons in addition to about 30 tons of steel.

**The tower height is 50 m and the length of cable is assumed to be 55 m. The material of the cable is corrosion resistant steel with cast steel as sheave material. The standard wire diameter could selected 3/8 in. and weight per foot is $1.7d^2$ lbf. From this we can calculate the weight of 55 m cable = $50/.305 \times 1.7(3/8)^2 \times 12$=470 lbs or 136 kg.

*** The path and road construction materials are assumed to be stone and soil. The mass of soil and stone will change with the length of roads and path. It is assumed here that a 5 Km road was built and the total mass of soil is equal to 50 tons and the total mass of stone is equal to 100 tons.

**** The material used in site office construction is again concrete and steel. The mass of materials will depend upon the rooms at the site; however, it could just be the main transformer room. The mass of steel and concrete materials used are assumed to be Steel = 5 tons and Concrete = 10 tons.

### *4.4 Wind Farm Operation and Maintenance*:

The embodied energy of wind farm operation and maintenance are calculated as follows:

*Steel:* Total steel = 223+30+0.136+5 = 258.136 tons, Steel cost = 258.136 tons*1000 $/ton = $258136
*Copper:* Total copper = 65 tons, Copper cost = 65*7000=$ 455000
*Aluminum:* Total aluminum = 116 tons, Cost of Aluminum = $ 348000
*Glass Fiber:* Total glass fiber used = 52 tons, Cost of glass fiber =$ 338000
*Permanent Magnet:* Total permanent magnet used = 332 tons, 10kW permanent magnet for wind farm can be bought at about $14,000. (Anhui Hummer Dynamo Co. Ltd, China).
*Concrete:* Total concrete used = 750 tons, Total concrete cost = $ 48750
*Stone:* Total stone used = 100 tons, Stone Cost =100 tons * 1000 $/ton = $ 100000
Total Material Cost = $ $1.67 \times 10^6$
The total cost is calculated as follows:
Total cost = Material Cost + Overhead cost; Overhead cost = 25% of Material cost
Total cost = $ $1.67 \times 10^6 + 0.25(1.67 \times 10^6)$ = $ $2.0875 \times 10^6$

Table 5: Wind Farm Activities as Proportion of Cost

| Category | Proportion (%) |
|---|---|
| Administration | 21 |
| Insurance | 13 |
| Land Rent | 18 |
| Miscellaneous | 17 |
| Power from Grid | 5 |
| Service and Spare parts | 26 |

The average proportion of cost associated with the operation and maintenance of wind farm is as follows: From the total cost, proportionate costs for different categories are calculated. Categories are; Administration, electricity generation and distribution; Insurance; Miscellaneous, electricity generation and distribution; Service and spare parts, machinery and equipment maintenance; Power from Grid, electricity generation and distribution.

Life Cycle O& M costs = Total cost* Energy Intensity (GJ/$) * Plant life (20yeras)
The energy intensity coefficients from (Ashby, 2009) were used to calculate the embodied energy.

### *4.5 Wind Farm Decommissioning and Land Reclamation*

The energy embodied in wind farm decommissioning and land reclamation was assumed to be zero. The energy associated with wind turbine dismantling was already calculated in turbine production and dismantling. It is also stated in (Kutz, 2007) and (Jha, 2016) that the recycling and scrapping of the wind turbine has a negative embodied energy. This represents the energy gain because of the lower energy embodied in recycling the materials when compared to the extraction of the materials in their raw state from earth. It was assumed that the energy embodied in the other stages of plant decommissioning cancels out with the energy gain in recycling of turbine materials. The land reclamation embodied energy is assumed to be nil.

## 5. Conclusion

The proportion of energy embodied in the various phases of the Wind Farm's life cycle is shown below in Fig. 12. The wind farm's life cycle is divided into 4 main phases. They are turbine production, turbine transportation, site construction and fixed assets, and operation and maintenance. The wind farm decommissioning and reclamation embodied energy is assumed equal to zero. The highest portion of the wind farm's life cycle energy is embodied in turbine production and dismantling, accounting for nearly 43% of the wind farm's total embodied energy. Turbine transportation and site construction and fixed assets contributed about 30% and 20%, respectively, of the total embodied energy. Wind farm operation and maintenance contribute only 7% to the total embodied energy. The direct energy of the wind farm corresponds to operation and maintenance, while indirect energy includes all the other phases of the life cycle. The life cycle cost will change according to the optimized structural design of the wind turbine. It will however, be dependent on design philosophy, whether for minimum weight or maximum strength. More research is needed to compare the different optimized design objectives.

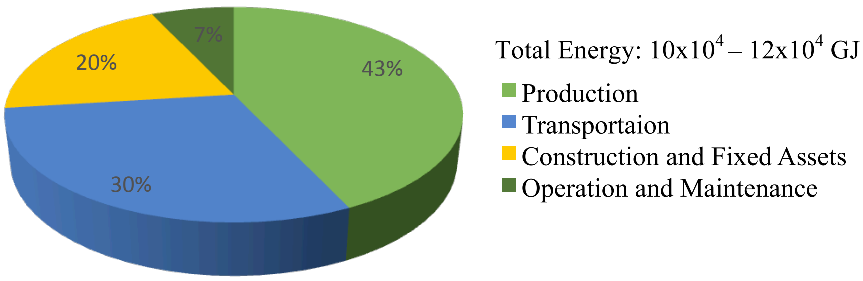



Figure 12: Proportion of Embodied Energy

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# The Value of Life Cycle Thinking: Valuable Links in Sustainable Engineering Education

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**Abstract**

Life cycle sustainability assessment (LCSA) has commonly been incorporated in sustainable engineering curriculum as a sustainability assessment and decision making tool. Life Cycle Thinking (LCT) is a concept that emphasises the need to understand the environmental, social and economic impacts of a product or service over its entire life cycle. This paper reviews how the Sustainable Engineering Group at Curtin University has incorporated the concept of LCT in a multidisciplinary engineering unit for undergraduate students called Engineering for Sustainable Development (ESD). This paper explores how this concept has been utilized to emphasise the value of LCT in forging an increased awareness and responsibility for whole of life cycle design and operation in the minds and skill sets of young graduate engineers.

## 1 Introduction

Engineers play a pivotal role in implementing sustainable development agendas. After the Earth Summit in 1992, a group of engineers identified that approximately 70% of the issues listed in the Agenda 21 Action Plan concerned engineering design, and at least 10% of these issues had major engineering applications (The Natural Edge Project, 2007). Universities across the world have been developing approaches to produce engineering graduates with the values, problem solving skills, knowledge, and attitude to create the capacity to apply the principles of sustainable development throughout their professional career. Sustainable development is a normative concept because it views the world not in the way it is, but in the way it should be (Wiek et al., 2011). Therefore the skills required by practitioners for sustainable development represent a meta-disciplinary endeavour, combining information and insights across multiple disciplines and perspectives with a common goal of achieving a desired balance among economic, environmental, and societal objectives (Mihelcic et al. 2003). This suggests a need for a range of sustainability metrics and methodologies such as life cycle thinking (LCT), system dynamics, multi-criteria decision making tools, and impact assessment frameworks in engineering education (University of Cambridge, 2016).

LCT can enhance the sustainable engineering curriculum by incorporating economic, environmental, and social consequences across the product or service life cycle. It identifies the opportunities to reduce environmental and social impacts during production from the extraction of raw materials, to the processing, manufacturing, assembly, distribution, use and ultimate disposal stages.

A key aim of LCT is to avoid burden shifting (European Union, 2010). This means minimizing the impacts at one stage of a product life cycle, or in a particular geographic region or impact category, while avoiding increases in other production stage(s).

LCT encourages the examination of the entire product value chain– by designers, planners, manufacturers, engineers, consumers, and recyclers – to consider from a holistic perspective the life cycle of products/services, and more specifically, to understand the inputs (including resources such as energy and water) and outputs (emissions to the environment) that result from the transformation of resources into a product, from a product to service, and from service to end of life disposal.

LCT is fundamental in holistically assessing the sustainability of products and services and can be used by decision makers in the private and public sector in the development of sustainable products, in green procurement (e.g. organic fertilizer, bio-fuels, recycled composites, solvent free paints) and the provision of environmentally friendly services (e.g. solar electricity, 3D printing) (UNEP, 2016; Klöpffer, 2003).

The most well known application of LCT is in Environmental Life Cycle Assessment (E-LCA), normally referred to as Life Cycle Assessment (LCA) analysis, which was developed by industrial ecologists to evaluate the environmental impacts of products and services during all phases of their life cycle (McConville, 2006, UNEP, 2012). In recent times, there has been a great deal of progress made in the development of LCA methodology, allowing engineers to more holistically assess environmental impacts across all stages of production, use and end of life (EoL) disposal of a product (Mihelcic et al. 2003). LCA enables engineering students to consider the application of 6Rs (reuse, reduce, remanufacture, redesign, recycle and recover) to reduce environmental impact as well as reduce raw material input, energy use, processing time, and associated costs of production (Meo et al. 2014).

Life cycle thinking can also be used in design for environment applications and the redesign of a product to meet legislative requirements, including design for recycling and dis-assembly, and input substitution (Jensen and Remmen, 2005). LCT can assist in the conservation of natural resources and a reduction in land use, therein increasing the carrying capacity of the earth by decreasing the ecological footprint associated with production, consumption and waste disposal. Intergenerational equity can as a result be significantly enhanced. A reduction in chemicals and energy use in the product life cycle can also provide intra-generational equity benefits.

LCA has also been found to be an important component in a review of Engineering Sustainability courses in the UK and USA. According to the Royal Academy of Engineering (2005), LCA was considered to be one of the top four skills for a graduating engineer. Finnegan et al. (2013) reported that as a result of increasing demand from industry, LCA has been included in the built environment curriculum across a number of US and European Universities. An Australian study by Shah and North (2010) found that the demand for LCA skills within the Australian workforce was increasing, also highlighting the increasing industry application and value seen in LCT.

There is currently little published literature that discusses the application of an LCT approach in engineering education (McConville, 2006). Lin et al. (2012), in their paper on life cycle thinking discussed the application of LCA as a construction management tool, but they did not explicitly discuss supply chain management and other socio-economic implications. In the Clarkson University model (Powers et al. 2011), LCT is taught as a part of an Industrial Ecology unit, which involves students in exercises utilizing LCA to identify potential environmental solutions. By comparison, RMIT University, Melbourne, offers an entire unit on life cycle assessment course for undergraduate engineering students (Crossin et al., 2011)

The Sustainable Engineering Group (SEG) at Curtin University in Western Australia have been teaching a core engineering unit in 'Engineering for Sustainable Development' to undergraduate students for more than a decade (Rosano and Biswas 2015). This paper examines how this undergraduate engineering unit has embraced the concept of life cycle thinking to enhance the value and importance of sustainability management education in an undergraduate engineering degree.

## 2 Teaching LCT to Curtin Engineering students

The unit on Engineering for Sustainable Development (ESD) is mandatory for all engineering students in the School of Engineering at Curtin University. It is typically taken by 2nd and 3rd year BEng students. ESD deals with the contribution of engineering technologies and processes to the development and implementation of sustainable solutions using life cycle thinking principles. The pedagogical approach for teaching LCT to ESD students involves both passive and active learning techniques.

The passive learning provides a conceptual understanding of LCT through well-structured theory intensive lectures, case study presentations and topical sustainability related reading materials.

The problem based active learning gives the students an opportunity to solve open ended and complex real world problems in supervised workshops and through assignments. The students are provided with the activities to develop a LCA framework where they learn to work collaboratively in solving the given sustainability problem. This problem based active learning has been found to improve knowledge development and the skills required in solving multi-discipline problems. In addition students need to initiate the problem solving collaboratively and in doing so develop a better understanding of the importance of ethical conduct and group communication in solving complex sustainability challenges (Steinemann, 2003).

Similar pedagogical approaches have been found in the literature. The University of Washington (UW) has incorporated LCT into their civil and construction engineering coursework (Lin et al. 2012). Following the lectures, students are given a series of assignments that also use an LCA framework. Clarkson University provide LCT education through a unit on Industrial Ecology, which is followed by exercises utilizing an LCA framework to identify potential solutions for supply chain environmental improvement (Powers et al. 2011).

## 3 Enhancing LCT through the application of Life Cycle Sustainability Assessment

Whilst Life Cycle Sustainability Assessment (LCSA) is an effective approach in the teaching of Life Cycle Thinking concepts (UNEP 2012). SEG have successfully used LCA in an undergraduate teaching unit (ESD) in the teaching of sustainable product design, strategies for enhancing engineering sustainability, as a decision making tool in engineering management and to assist student critical thinking development.

### *3.1 Sustainable product design*

Students learn that LCSA is a ‘sustainability assessment tool’ to help identify hotspot(s) where the inputs or processes causing the most environmental or social impact. Environmental Life Cycle Assessment (E-LCA or LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) are established LCSA tools specifically designed to address these impacts during the life cycle of products/services. In addition to LCSA, ESD also covers the following industrial ecology topics that are taught to enable the students to apply mitigation measures across the product life cycle to achieve more sustainable engineering outcomes.

<u>Design for the Environment</u> (DfE) aims to minimise significant environmental impacts and increase resource efficiency at all stages of a product’s life cycle – from raw material extraction and processing, to manufacturing, packaging and distribution, product use, and the end-of-life disposal. Students learn eight eco-design strategies, including new concept development (e.g. delivering services instead of selling product), use of low impact materials (e.g. vegetable ink), renewable materials (e.g. compostable

plastic made of biopolymers derived from corn to replace petrochemical based plastic), reduction of material usage (e.g. aerogel, carbon fibre composite), optimisation of production techniques, and optimisation of distribution systems (e.g. designing packaging system so that more items can be transported in one trip), designing a product cost effectively with reduced energy and material consumption and designing a product for reduced environmental impact. Importantly, the students also learn that the initial design of the product is important as it can make the end of life products more suitable for reuse, recycling and remanufacturing.

### *3.2 Strategies for enhancing engineering sustainability*

Cleaner production and eco-efficiency strategies - Cleaner production strategies (CPS) are selected to reduce overall environmental impacts in a cost effective way. Students are given examples of CPS that not only reduce environmental impacts e.g: turning waste into resources but also to achieve economic benefits from higher cost benefit ratios, and shorter pay-back periods. Students learn that the application of CPS can help restructure environmental supply chains to assist in reducing life cycle impacts.

Students also learn that CPS can help achieve eco-efficiency (i.e. doing more with less) improvements. A workshop activity on incandescent lamps versus compact fluorescent lamps (CFL) focuses on the initial additional cost of the CFL being offset against reduced operational costs and reductions in environmental impacts, de-linking growth from environmental impact. In practice, cleaner production and eco-efficiency can be regarded as ‘two sides of the same coin as they are rooted in environmental prevention strategy (Van Berkel, 2006). They go beyond pollution prevention by explicitly incorporating conservation of materials, energy, and other natural resources for the future generations and by value adding to production to help achieve a more sustainable future.

Industrial Symbiosis - In addition to CPS, students also learn that they can consider Industrial Symbiosis (IS) as a mitigation strategy in product life cycle management, where neighbouring production industries can share their waste, by-products and outputs with reduced dependency on the use of virgin materials and waste disposal. This strategy reminds engineering students of their responsibilities in designing ‘waste’ out of production systems and thinking of ‘waste’ as a potential resource material.

The concept of ‘source and sink’ are also taught to enable students to understand that the reduction in sink (or landfill) by converting waste/by-products at the end of life (EoL) to a resource, will ultimately reduce the amount of land required for mining and production and other associated upstream activities. Students learn how the application of the concept of industrial symbiosis can conserve energy, material, and natural resources increasing the carrying capacity of the earth and enhancing intergenerational social equity (i.e. leaving adequate resources for future generations).

Green engineering - Green engineering is integral in the development of sustainable technologies as it focuses on the systematic evaluation and improvement of the environmental performance of industrial processes, and the design of new processes and procedures that are as safe and efficient as possible. This is achieved through green chemistry (i.e. increased atom efficiency or maximising the amount of product with less waste creation), bio-technology (e.g. use of enzymes as a catalyst to reduce a number of chemical reactions/steps), nano-technology (e.g. photo catalytically active $TiO_2$ self-cleaning, anti-graffiti, and anti-fingerprint coatings), biomimicry (e.g. mimicking bird fight in designing an efficient aircraft), waste prevention instead of treatment, design for separation, and green design (e.g. recycled aggregates replacing virgin crushed rock limestone aggregates in pavement construction). A biomimicry teaching example on technological innovation shows how the behaviour exhibited by birds in flight can provide economic and environmental benefits when mimicked in aircraft aerodynamics. Where:

- reducing the wake results in lower pressure difference across the aerofoil

- this lower pressure differential creates lower force (drag) acting against the direction of motion
- lower drag (force) = lower power (force x velocity) required to maintain the same velocity
- lower power requirement means lower fuel consumption
- lower fuel consumption means lower environmental impact and improved economic performance

<u>Dematerialization</u> - Students are introduced to the concept of 6Rs, including reduce, reuse, recycle, redesign, remanufacture and recover that can potentially avoid energy and material consumption and associated environmental impacts during upstream activities using virgin resources. As a part of a workshop activity, students conduct an analysis on the carbon footprint of a Fuji Xerox multifunctional device (MFD), which performs the tasks of a fax, printer, photocopy machine, and scanner. Students determine whether or not to purchase a standalone photocopier, printer, scanner, and fax equipment or to purchase a MFD. Students also work out that the use of electronic communication avoids paper use that then results in a decrease in deforestation, land use change and further loss of bio-diversity.

Figure 1 summarises how the above industrial ecology topics are delivered in the ESD unit to assist students in enhancing their life cycle thinking skills in order to design more sustainable products and services.

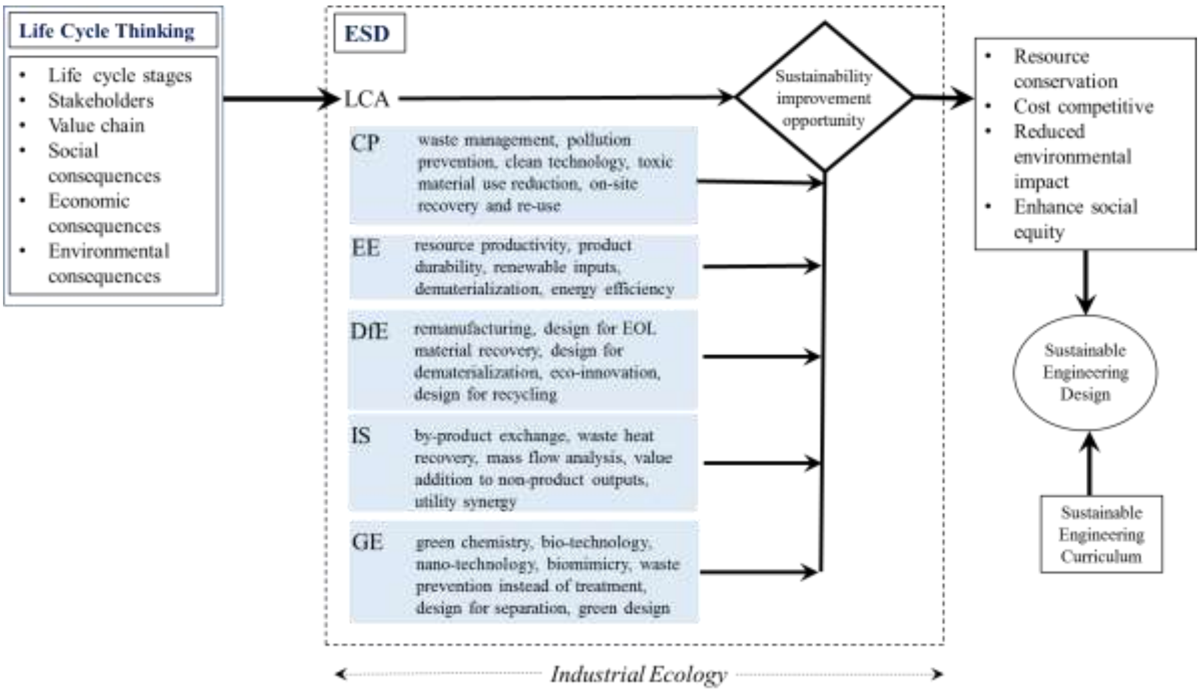


**Figure 1:** Relationship between life cycle thinking and sustainable engineering curriculum [CP – Cleaner Production, EE – Eco-efficiency, DfE – Design for the Environment, IS – Industrial Symbiosis, GE –Green Engineering] in the ESD unit at Curtin University.

### 3.3 *Decision making tool*

Students learn that LCA is a decision making tool that can be used to compare the environmental performance of products doing the same job. One example given is the comparison between fast food and dine in restaurant meals. When students compare the overall life cycle results that take into account the mining, processing, farming, packaging, disposal of pre-restaurant waste , use and disposal stages of food production, they discover that the dine in restaurant performs better than the fast food restaurant. LCT can be an eye opener for young engineering students in fully understanding the link between LCT and sustainable production and consumption and engineering decision making.

### *3.4 Critical thinking capability*

Students are given a number of case studies that show how the use of LCA can improve their critical thinking capability. For example, in a workshop case study, students initially believe that solar photovoltaic energy and biodiesel bio-diesel energy production are almost carbon neutral as they are considered a renewable energy source. However this perception changes when LCA results show that the manufacturing of solar PV panels and biodiesel crop production systems do produce emissions that also need to be managed and minimised through cleaner production and eco-efficiency strategies.

In another example, on a comparison between corn based plastic (PLA) cup and polystyrene (PS) cups, students discover that the latter is more environmentally friendly than the former. The students are unable to comprehend this initially as they consider corn a renewable resource. Corn based plastic has been found to be environmentally friendlier than polystyrene on weight basis, but not on volume basis. The student's perception changes when they realize that the function of the cup is to hold liquid, so space/volume matters. Since the PS cup is lighter than PLA cup, it requires less material to provide the same utility volume and therefore, the PS cup turns out to be the more environmentally friendly option. Whilst this comparative LCA outcome can change dependent on the choice of transportation and method of environmental impact estimation (S. Madival et al., 2008; Harst and Potting, 2013), students are able to understand that something 'natural' is not always the most environmentally friendly option, which in turn suggests a need to investigate sustainability assessment methodologies to more accurately support critical thinking in engineering decision making.

## 4 LCT teaching examples

SEG have developed a number of multidisciplinary comparative (functionally equivalent product systems) LCSA problems (Diesel *vs* Hydrogen fuel (SMR/AE) bus, Diesel *vs* Bio-diesel electricity generation, Ground water *vs* Desalinated water production, Metal halide lamp *vs* LED lamp, Front loading washing machine *vs* Top loading washing machine, Hydrated Lime *vs* Lime kiln dust) and other stand-alone LCSA service problems (Overhead power transmission networks, Residential buildings, and Waste water treatment processes). All these examples have been developed based on real world data on material and energy inputs including emission factors. These LCT focused teaching examples help the students to develop systems thinking, anticipatory assessment, and inter-disciplinarity focus (Wiek et al., 2011, Dentoni et al. 2012). A diesel *vs* Hydrogen powered bus case study highlights the triple bottom line implications of the replacement of diesel with hydrogen fuel from a life cycle thinking perspective. The economic, social and environmental implications of pre-manufacturing, manufacturing and use (combustions stages of the fuel cycle) are considered not only to determine the most sustainable fuel but also to identify further improvement opportunities in making the fuel more environmentally friendly and cost-competitive. At the same time, students are applying a systematic procedure of life cycle assessment that allows them to determine a framework for comparative product/service sustainability assessment.

Firstly the students apply LCSA to estimate social, economic and environmental impacts of two fuels for comparative purposes. Secondly, they explore the opportunities for triple bottom line improvement by identifying the stages or inputs with the highest impact. Thirdly, they review the literature to determine appropriate CPS and eco-efficiency, industrial symbiosis, and green engineering strategies to improve overall sustainability. Finally, they revise LCSA results by incorporating these mitigation strategies to calculate mitigation/saving potential.

In calculating the sustainability improvements, material, energy, cost, associated social data, and emission factors related to diesel operated and Hydrogen operated buses is provided and students are asked to complete the following tasks:

Task 1 - Calculate the GWP and acidification from the production and use stage of diesel for the internal combustion engine of buses for the functional unit and then calculate the GWP and acidification from the production and use stages of hydrogen fuel in the fuel cell of buses to determine the environmental implications of this substitution.

Task 2 – Identify the ‘hotspots’ or input(s) or process creating the most environmental impact.

Task 3 – Calculate the costs associated with the production and operation stages of both options.

Task 4 – Determine the social impacts associated with both options

Task 5 - Discuss the potential mitigation strategies for treating the GWP and acidification hotspots and clearly mention the source/s of information on mitigation strategies.

Task 6 - Discuss using a triple bottom line matrix how (the) the engineering improvements like those in the example can assist sustainable development from an economic, environmental and social perspective.

## 5 Discussion

To analyse the learning outcomes from the life cycle thinking approach taken in this unit, the results from different learning tasks/assessments have been broadly analysed. The number of students enrolled in the ESD unit has been increasing over last few years with typically more than 500 students enrolled each year. The assessment criteria for these tasks has been developed based on the Engineers Australia’s stage 1 competency standards for professional engineers. These competencies cover 16 mandatory elements of competency including knowledge, ability, values and professional attitudes.

Within the workshop format two separate tasks focused on the development of Triple Bottom Line Assessment methodologies and an E-LCA assessment are assessed. The TBL assessment focuses more on a qualitative assessment of potential environmental impacts whilst the E-LCA assessment gives students the opportunity to quantitatively assess the environmental impacts in terms of GHG emissions.

In the quantitative E-LCA assessment, students over the past 5 semesters (S1 2014- S1 2016) have achieved overall marks between 70% to 100%, highlighting an expected engineering predisposition for numerical assessment and analysis. Students enjoy the E-LCA task given its quantitative nature and systematic and logical approach in assessment. In this assessment students learn to develop LCIs (life Cycle Inventories), estimate environmental impacts, identify the production hotspot(s) creating the most environmental impact, and then exploring and implementing mitigation strategies to reduce the environmental impact, and finally re-estimating the environmental impacts after the application of the mitigation strategies. The students then present the work in report form including lessons learnt from the assignment. The detailed feedback helps the students to analyse their performance and improve their understanding of environmental impact causation and mitigation. The E-LCA tasks are generally worth 15% to 20% of total unit assessment.

In the TBL task, students are required to investigate some of the more qualitative perspectives in sustainability assessment. Students are required to develop their own ‘sustainable development’ indicators including technical and indigenous culture indicators. Students then analyse the potential impact of these indicators and discuss their effectiveness in achieving the goals of sustainable development. The TBL tasks are generally worth 20% to 25% of total unit assessment and the majority of students achieve marks between 70% to 90% in this assessment.

When compared to the E-LCA task, students typically have shown less interest in the development of qualitative indices to represent sustainability performance. ESD Lecturers and Tutors have reported that it is more challenging to teach TBL methodologies as the students find it more difficult to understand the relevance of social values and future consequences than the more tangible GHG emissions based assessments from E-LCA. Whilst assignment questions and unit delivery slightly change from semester to semester, Figure 2 nonetheless demonstrates the difference between student’s quantitative and qualitative performance in sustainability assessments for the individual E-LCA and TBL assessments.

After completing these tasks and with subsequent assessment evaluation feedback, the majority of students achieve a significant improvement in their understanding of the two different but equally valuable sustainability assessment methodologies.

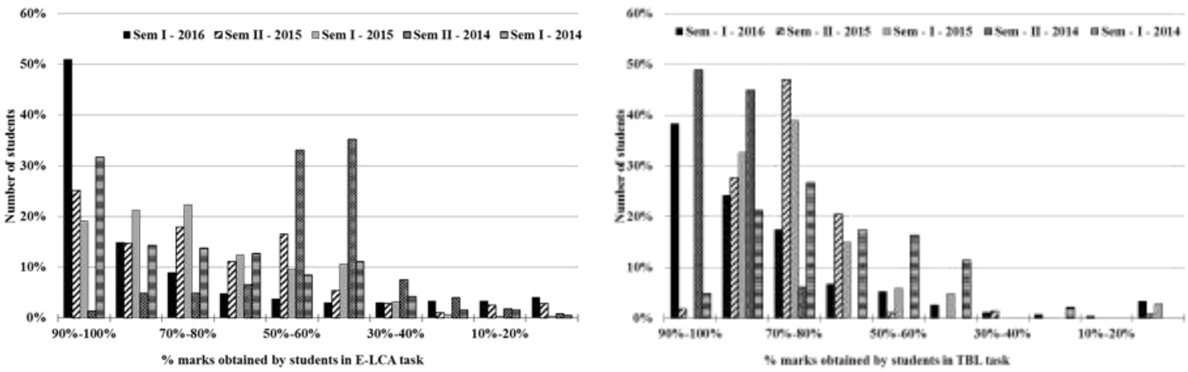


Figure 2: Student’s performance on E-LCA and TBL tasks across S1 2014- S1 2016

## 6 Conclusions

Many universities who teach sustainable engineering units include LCSA as a useful sustainability assessment tool without explicitly highlighting the need or importance for LCT. LCSA is used to demonstrate life cycle thinking and goes beyond simply quantifying environmental or economic impacts to further demonstrate the valuable links for sustainable engineering curriculum. LCSA also allows other sustainable engineering topics including CPS, eco-efficiency, industrial symbiosis, design for the environment, and green engineering to be incorporated in design process and sustainability management in the engineering curricula.

The concept of LCT has been embraced to teach future engineers what factors they should consider in the engineering decision making to achieve sustainability outcomes. The assignments, relevant theories and workshops based on LCT, help to improve the critical thinking ability and environmental decision making skills of young engineers as well as enhancing their ability to design sustainable products and systems.

LCT is a way of linking design processes and product development from a systems perspective, which allows for the identification of environmental, economic and social hotspots across the product life cycle in engineering education.

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# Teaching of Life Cycle Assessment methodology to sensitize future engineers to sustainable development

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## Abstract

The aim of this paper is to present the teaching approach which has been followed concerning the Life Cycle Assessment methodology (LCA). This course was launched three years ago by the Chemical Engineering Department, being aware of the potential of this methodology but also the pressure demand of LCA in industries.

When looking at the Engineer curricula, especially the one of the chemical engineers at University of Liège (ULg), students have a background on environment mainly relative to the technologies to be used to treat air or water pollution. Another approach of environmental issues has been offered to students of the second master in chemical engineering, to increase their knowledge with the learning of the LCA methodology. Before creating this course, these students had only a brief 2 hours lecture, given for more than 10 years as an introduction to LCA to all the students in the second bachelor in Engineering.

LCA teaching activities rely on an expertise developed for more than 15 years as a research domain within the Department. LCA is a methodology used to assess the environmental potential impacts of a product during its overall life cycle, taking into account all stages from the raw materials extraction to the end-of-life.

The course is divided in three parts. First, the environmental context is drawn with the highlighting of the main challenges for the current generation and the future ones. Secondly, the LCA methodology is taught going through ISO standards using mainly applied exercises and several examples of published studies. An introduction to environmental labelling is also given. Students also learn to use a software to model scenarios and obtain results. Teachers give a special attention to show them, using previous examples in the course, the interface function of the tool and the importance of data quality. Results must be explained and justified using their critical thinking. Finally, students are evaluated on a project performed by group of 2 persons. They must criticize, using their acquired knowledge, a scientific paper related to a published LCA study. They must remodel scenarios based on the available data and compare their results with the published ones.

Teachers do not evaluate the modelling results obtained by the groups but the approach they use and how they interpret the results. The main goal of this type of pedagogy is to form future engineers, aware of the future challenges concerning environment and with the sufficient background to manage and to tackle these issues.

## 1 Introduction

Life Cycle Assessment (International Organization for Standardization (ISO) 2006b; International Organization for Standardization (ISO) 2006a) is a quite new method to assess environmental impacts of a product during its whole life cycle, allowing the avoidance of trade-off between impact categories or steps of production. Even if it is more and more used by policies but also by industrials to assess their environmental impacts and to help decision, this concept is not always included in the teaching program of future engineers.

Some attempts to include LCA in the educational background of engineers have been performed in several countries, using different pedagogic methods. An educational experience has been conducted in Brazil during 6 years with the UNEP/SETAC Life Cycle Initiative (de Souza Xavier et al. 2014). Another experience has been lead in the USA, where sustainability was introduced in an existing course with a dedicated module to LCA (Paudel and Fraser 2013). LCA has also been implemented as several learning games in a engineering course in Italy (Bevilacqua et al. 2015).

This paper explains the implementation of a new LCA course in the cursus of chemical engineers in the University of Liège in Belgium, the reason of its implementation, its goals and what was expected for and from the students. Some perspectives of improvements are also highlighted.

## 2 LCA implementation in the University of Liège

### *2.1 Specific context in Liège*

Life Cycle Assessment methodology is a recognized tool to help assessing sustainability and opening minds about environment. In that context, it is a powerful tool that any engineer who will work in industry, academic or public organizations should be aware of.

When focusing on the background of engineers of Liège, and more specifically on chemical or mechanical engineers, some specific knowledge about environment is included in their educational programme. These courses are relative to technologies to be used to treat air or water pollution, so to act downstream. Sustainability in terms of environment is more related to upstream actions as eco-design or processes improvements. As future engineers are also the future designers of our next products, they need a specific knowledge of how to select the best materials and adapted processes being in accordance with the 12 rules of the Green Chemistry (Marques 2014).

Furthermore, one group of the Chemical Engineering research unit has developed an expertise in the LCA field for more than 15 years. Participation of projects from the conception phase of a product until the industrial production has highlighted the need of the integration of environment at each phase of the development of this product.

Aware of this lack in the engineering background of our students, a new course has been launched three years ago for students of the second master in chemical engineering, called Eco-design and LCA. Before creating this course, these students had only a brief 2 hours lecture, given for more than 10 years as an introduction to LCA to all the students in the second bachelor in Engineering.

### *2.2 LCA course*

The course, as given in their last year of study, can be seen as an integrated one, gathering all their previous knowledge about mass and energy balances but also about pollution and environmental treatments.

This course is divided in three parts with a first part based on learning, the second part related to practising and the final one linked to acting and opening their mind.

The first part based on learning highlights the main challenges for the current generation and the future ones in terms of environment. Discussions are opened with students asking them their thoughts about several current topics as e.g. climate change, water depletion, acidic rains, etc. After this, the concept of environment and current regulations and tools are drawn to explain the context where they live.

The second part is dedicated to the teaching of the specific LCA methodology going through ISO standards using mainly applied exercises and several examples of published studies. A first exercise comparing popcorn and polystyrene chips to fill a box based on their environmental performance is performed as introduction of this methodology (Jolliet et al. 2010). Other examples are used to illustrate some green ideas put in their mind by advertisements or intuition and showing the importance of a complete tool taking into account the whole life cycle of a product to avoid trade-off in terms of steps but also in terms of pollution. To develop their critical thinking, first homework of students is to analyse a published article, to criticize it in terms of environmental relevance and to evaluate if it is in accordance with the ISO standards.

As this second part is dedicated to practice, students also learn to use a software to model scenarios and obtain results. Teachers give a special attention to show them, using previous examples in the course, the interface function of the tool and the importance of data quality. Results must be explained and justified using their critical thinking. Same exercises are proposed to all students, to show how to model and implement scenarios in the software, as well as how to perform energy and matter balances without any software. The most important thing is to analyse results and to understand the limitations of the tool and when its use is not relevant.

The third and final part of this course is a group project focusing on a scientific paper, different from one group to another based on different topics going from insulation and building conception to food going through transport. They receive randomly their topic and must work together to criticize the paper, showing its environmental relevance and its (non)-accordance with the ISO standards using their acquired knowledge. They must also remodel scenarios, using the software and the available data. The goal of this part is to understand the difficulty of the modelling and the importance of choices relative to databases. They have also to compare their results with the published ones and to explain why they obtain this kind of results and what the origin of the differences is. Teachers do not evaluate the modelling results obtained by the groups but the approach they use and how they interpret the results.

## 3 Conclusions and perspectives

The new course related to Life Cycle Assessment is a first attempt to add, to the educational background of future engineer from Liège, a competence linked to sustainability which can help them to tackle future issues and challenges concerning environment.

This course of three years old has been improved through years, collecting the advices of students and the feeling of teachers concerning the content and the reactions of students. For example, the real work concerning project and the associated modelling have been reduced through years to increase the time dedicated to the interpretation phase. Indeed, this phase is essential to act against greenwashing and increase the awareness of students about the importance of being transparent and relevant to the subject.

The main drawback of this course is the essential focus on environment which is only one of the three pillars of sustainability. Economic and social fields are briefly introduced in this course but due to time and required competences, are not taught in an exhaustive way. An interdisciplinary course could be envisaged for a next future including concepts as circular economy or social justice as it was the case in the USA (Riley 2015).

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# Immersive policy education & Science Outside the Lab: Preparing engineers & scientists to guide technological development in transdisciplinary and cross-sectoral environments

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**Abstract**

In most democratic countries, the domain of technology policy is broadening, creating new and changing roles for engineers in policy and public spheres. At the same time, the transformative potential of new and emerging technologies, and environmental, economic and social crises, raise the stakes of technology policy. Within this context, engineers – whether working in large companies, small start-ups, universities, for government, or for non-governmental organizations – play multiple roles as innovators, experts, technology users, and citizens. In order to contribute to sustainable and just technological development, engineers must understand policy processes in the real world. They must also develop the skills to engage with stakeholders from different sectors and collaborate with others who have different disciplinary training and worldviews. To accomplish these goals, Arizona State University has created a series of two-week policy immersion short courses that have been run for over a decade in Washington, D.C., USA. The program is now being expanded and will be offered for the first time in Ottawa, Ontario, Canada. In this paper, we present a brief overview of the pedagogy and design of these courses in both the United States and Canada. We use preliminary data from a pre/post survey to investigate potential impacts on the students participating. We then turn to informal qualitative evaluation of the Canadian program we conducted during its first iteration, highlighting possible positive outcomes and areas for future improvement. These results offer a series of possible lessons for other scholars and practitioners who wish to develop similar courses in other countries.

## 1. Introduction

In many countries around the world, the domain of science, technology, and engineering policy is broadening. In some situations, this is driven by the increasing complexity of techno-scientific problems like climate change, humanitarian crises, and development (Allenby & Sarewitz, 2011); in other contexts this is related to evolving norms and expectations about the responsibilities of scientists and engineers (Stilgoe et al., 2013). Regardless of the cause, scientists and engineers are faced with expanding roles in policy and public spheres.

At the same time, simple and unexamined linear representations of how decisions are made, how innovation is supported, and how scientists and engineers might engage in policy are no longer satisfactory or well founded (Balconi et al., 2010). Many nations are also striving to democratize scientific and innovation processes, whether to adopt more systemic and participatory mechanisms of technology policy (Guston & Sarewitz, 2002), or to benefit from the increasing monitoring value of movements like citizen science (Kennedy, 2016). Moreover, the transformative potential of new and emerging technologies – alongside environmental, economic, and social crises – raise the stakes of scientific and technology policy.

Within this broad policy context, engineers and scientists (whether working in large companies, small start-ups, universities, government, or non-governmental organizations) play multiple roles as innovators, experts, technology users, and citizens. In order to contribute to innovation, engage with the complexities of technology creation and progress, and determine how to contribute to just and sustainable development, engineers and scientists must understand policy processes in the real world. They must also develop the skills to engage with stakeholders from different sectors and to collaborate effectively with others who have different disciplinary training and worldviews.

To accomplish these goals, Arizona State University (ASU) has created a series of policy immersion short courses developed for engineers and natural scientists. Entitled *Science Outside the Lab* (SOtL), the courses have been run for over a decade in Washington, D.C., USA. In 2016, authors Kennedy & Harsh developed a Canadian variant of the course to run in Ottawa, Ontario and Montréal, Quebec, Canada for graduate students (MSc, PhD) and postdoctoral fellows in engineering and science.

In this paper, we present a brief overview of the pedagogical design and objectives of the course. We then examine the structural and cultural differences in offering this program in the Canadian context. We present some initial results from a pre/post survey of student attitudes about science, technology, and engineering policy, as well as a few high level themes from ongoing qualitative evaluation of the program. Finally, we discuss future directions for the Canadian version of the program and for the development of education evaluation methods.

## 2. Science Outside the Lab – Format, Structure, Pedagogy

The Washington, D.C. version of Science Outside the Lab (SOtL) was developed by the Consortium for Science, Policy & Outcomes at ASU - particularly Dr. Ira Bennett - and dozens of faculty and teaching assistants who have led the program over the past decade. At a high level, SOtL aims to complement the formal education of engineers and scientists who may one day shape research and policy from laboratory, business, government, or non-profit positions. The SOtL D.C. program aims to provide students with the tools to understand and reflect on:

- the difficulty and complexity involved in developing science and technology policy;
- how these complexities impact relationships among science, engineering, and society;
- the roles of science and engineering expertise in science policy; and
- the limitations of scientific information in resolving values-based policy debates.

The two-week long program is based on an immersion-based learning approach wherein students meet with a wide variety of experts from the D.C. policy arena. By placing program participants in a new context, separate from many existing social and academic pressures, they are offered time to inquire and reflect on the relationships between science, engineering and society. Over the program, they engage in approximately 20-30 ninety minute conversations with those who fund, regulate, shape, critique, publicize, and study science and technology, including government experts, funding agency officers, technology-focused interest groups, professional associations, science and technology journalists, academics, museum curators, and others. The conversations are unstructured, involving a short (5-10 minute) introduction by the speaker on their roles, responsibilities, experiences, and their journey to their current position. Speakers are chosen to represent diverse stages in a professional career, ranging from established experts to recently graduated scientists and engineers from various D.C. institutions. Through student-driven questions, the cohort learns about how policy decisions are made, how their own work is relevant in the policy sphere, and the skills they will need to collaborate with those making and shaping decisions.

The SOtL D.C. program generally begins with a full day spent on communication training, wherein students begin by sharing a brief presentation of their work. Under the instruction of an expert in science communication, they work to iteratively shorten and refine their presentations into 'elevator pitches' that they can use when introducing themselves and their work to the experts they meet throughout the week. The program also includes a short 'crash-course' on policy-making in Washington, D.C., as well as one or two lectures by visiting experts throughout the week on particularly technical components (e.g., budget, passing legislation, etc). Finally, SOtL generally involves a few sessions focused on communication in different genres, where the students participate in assignments writing about their work in different policy-relevant formats (such as a policy memo, press release, or briefing note). Throughout the program, students are encouraged to reflect about their experiences and learning over mealtimes and breaks.

Over the past decade, this program has become sufficiently well attended as to allow multiple variations to be run each summer. Some are two-week general SOtL programs, with an audience of primarily natural science and engineering graduate students. Others have taken on a more specific topic focus, such as energy policy or science diplomacy, and may run for only one week. Still others are run for a particular cohort, such as the annual SOtL program required for graduation from Arizona State University's Masters degree in Science & Technology Policy. The majority of students are funded by university laboratories (via federal grants) as a way of meeting grant requirements about broader impact, skills development, and professional development. A few students attend out of personal or professional interest. The program costs $4,000 USD for the two weeks, which includes accommodation and some meals.

## 3. SOtL North – Structural and Cultural Differences

Although SOtL and other programs offer this kind of learning experience in the United States, few opportunities exist for Canadian engineers and scientists who wish to learn about their home policy and political context. As such, in 2015, a team from Arizona State University (Kennedy), Concordia University (Harsh), and the University of Waterloo (Dr. Heather Douglas) began developing a version of the program to run in Canada. For the first year of the program (2016), we generally adopted the core attributes of SOtL D.C., including the student-driven conversations with experts, a brief amount of communication training (in our case, approximately three hours on the first day), and similar shared meals and breaks for informal reflection. The program was run as a seven day version (Sunday evening to Saturday evening) to focus logistical efforts and to engage students who were unable to take a full two weeks away from their research.

Several additional changes had to be made to make the program appropriate for a Canadian context. Because of the structure of politics and policy in Canada, the program began in Ottawa, Ontario (the national capital) and moved to Montréal, Quebec (the largest francophone city in the country) to learn about both English- and French-speaking science policy and science culture. As grants in Canada are generally smaller, less money is available to labs to fund student attendance and many students self-funded to attend. As such, while still including accommodation and most food (as well as transportation between Ottawa and Montréal), the program was designed to cost about $1,250CDN per participant, which was further subsidised with a small development grant. The initial communication training was shortened because of the program length and anticipated student preparedness.

## 4. Quantitative Evaluation

To evaluate the effect of the SOtL North program on participants' perspectives, we employed a modified version of a survey implemented in SOtL U.S. by Bernstein et al. (*under review*). The original survey was developed through a gathering of 44 key ideas about the relationship of science, society, policy, and scientist/engineer expertise. These ideas were gathered into conceptual clusters, resulting in 15 'scales' about participants' attitudes on the relationship between science and society. A 5-point Likert-type scale survey (ranging from strongly agree to strongly disagree) was then developed, using positively and negatively framed items for each of the 15 scales to reduce response biases.

In the modified SOtL North survey, the participants ($n$=9)[1] were prompted to "rank the extent to which you agree or disagree with the following statements" with on a 7-point Likert-type scale (1=strongly agree; 2=disagree; 3=somewhat disagree; 4=neither agree nor disagree; 5=somewhat agree; 6=agree; 7=strongly agree). We analyzed within-subject pre-post changes to the means of participants' answers on each of nine reliable scales, as well as one additional item about program impact. Because of the short length of this paper, we present only a handful of the items. A full breakdown of the survey scales, example questions, and statistical analysis can be found online.[2]

The nine scales assessed SOtL North participant perspectives on four broad themes. Pre and post program comparisons on questions related to the relationship between scientific progress and societal benefit showed no statistically significant difference: participants continued to see, for instance, basic research that informed technical design and engineering applications as yielding societal benefits. A second theme – the role of information in policy choice – also failed to show statistical significance, with participants continuing to agree that more technical information would equip policy makers to make better decisions. In general, participants broadly continued to maintain agreeable attitudes to the importance of science, technology, and engineering in society and policy decision making.
Two themes, however, did show marginal – if slight – shifts in participant attitudes following completion. First, participants felt slightly less likely (statistically significant at $p<0.05$) to advocate participating directly in policy decision making, either for themselves (e.g., "I should engage with policymakers to ensure that political debate is informed by the best available knowledge") or their work (e.g., "the knowledge I provide should be used to help solve societal challenges"). Second, participants were slightly less likely (statistically significant at $p<0.1$) to believe that science and engineering research were "the most important factor" for shaping policy, and slightly more likely to believe that "scientific and technological advances are necessary but not sufficient for resolving science and engineering policy debates."

These results are difficult to interpret from the quantitative data collected. While the latter results on the relationship between science and policy seem to suggest an increased sense of the many inputs to

[1] Note that at time of analysis, only 9/12 participants had complete post-program data, so the calculations included were done with only those participants.
[2] These resources can be found online at www.ericbkennedy.ca under "Papers."

the policy making progress – and that science and engineering research shouldn't be the sole arbiter of political decision making – the former results about personal engagement are harder to interpret. After encountering a wider variety of roles and institutions engaged in scientific policy making, participants may have left with an increased awareness of the other ways science can (and perhaps should) be integrated into decision making, rather than direct involvement themselves. It may correlate with being aware of the many other values that must be taken into consideration in policy decision. It could also represent a shift in how far 'upstream' they perceived their work to be, and perhaps a reduced suitability relative to the kinds of research they saw the guest speakers leveraging in their work. Further critical evaluation is important to more accurately interpret these results.

Many of these findings are aligned with those found in Bernstein et al.'s (*under review*) study of SOtL D.C. Like in SOtL North, participants generally both entered and left the program agreeing that scientists and engineers should be involved in parts of the policy process, and that science and engineering are and should be important factors in decision making (Bernstein et al., *under review*). Like in Canada, after the program, SOtL D.C. participants were less convinced that science or engineering research "were the most important factor" for shaping policy. Moreover, they too reported lower levels of agreement with the statement that they should individually "engage with policymakers to ensure that political debate is informed by the best available knowledge." A strong shift away from pro-linear model attitudes (e.g., more science automatically yields societal benefits) and a belief that science or engineering research "clearly demonstrates the need for certain policy decisions," however, suggests that the participants may indeed be developing a more nuanced understanding of how scientists and engineers can and should influence policy processes, rather than simply becoming disaffected with the process.

## 5. Qualitative Evaluation

Qualitative data came mainly from a debrief exercise at the end of SOtL and SOtL North. For this exercise, SOtL North participants were asked three open-ended questions: what they learned, what about the program did not work, and what about the program did work. The students drove the discussion of each of the three topics. Notes were taken in a way that the students could see (on a whiteboard and projected from a computer). An initial reflection on these debriefing notes suggests several potential positive outcomes of the program, each of which is worth further critical assessment and evaluation.

### *5.1 Appreciation of how policy works in the real word: complexity*

On several occasions during the debrief, students cited leaving the program with a greater appreciation of the complexity of science and technology policymaking. For instance, students commented on how they now better understood the structure of federal bureaucracy in Canada (the organization and relationship between government departments), and importantly, how this structure can sometimes hamper the creation and implementation of policy, despite the goodwill of all involved in the process. Along similar lines, the students mentioned the distinction between 'big P' and 'little p' policy, which was made by several speakers (the former referring to official law and positions, and the latter representing much of the day-to-day process of governing and administration). This nuance is important, as it involves the convergence of technical expertise and the mechanisms of bureaucracy through processes such as departmental reform, cross-departmental communication, and advisory panels.

### *5.2 Appreciation of how policy works in the real word: values*

Students also cited an increased understanding of the interactions between evidence and values in policy, science, and engineering. Representative comments during the debrief included remarks that “science is really not the only input in policy” and “just because it [science] is a little messy, it doesn’t make it completely non-credible.” In the first comment, one can see convergence with the initial quantitative findings, specifically that participants may become more open to the notion that factors other than science and engineering might be important and necessary for shaping science and engineering policy. The second statement was part of a rich discussion in the debrief exercise about the neutrality of science and engineering in themselves; the role values play in shaping the questions scientists and engineers ask; and how to articulate those values when engaging with policy makers.

### *5.3 Communication*

In the discussion, several students commented on developing a better appreciation about the power of how an idea is framed and communicated, such as how a new government initiative or position is named (there was much debate about the perceptions of two choices for a new government position: Chief Science Officer versus Chief Science Advisor). In the debrief, students also mentioned the importance of listening and effective communication when working with and within government. This theme emerged from a number of speakers, especially when relating accounts of working with individuals who have different expertise than one's own. Interestingly, while students appreciated the importance of communication, there was relatively negative feedback about including communication training (such as practice pitching their work or describing it to policy audiences) in the program itself.

### *5.4 Peer support and career development*

Several students reported finding a community of like-minded people (both in their fellow participants and in the speakers) interested in engaging at the intersection of science and engineering and policy. One student described being happy to learn that they weren’t “the only one who’s interested in these issues.” The students also learned about specific pathways to have a meaningful careers working at the intersection of science or engineering and policy (whether or not they choose to leave the academy).

### *5.5 Critical feedback*

Although the themes above indicate generally positive potential learning impacts (each of which will require more robust evaluation to assess validly), the debrief session also featured significant critical but constructive feedback from participants. Most significantly, there was a widespread agreement that the 90-minute ‘conversation with an expert’ format, as implemented like in SOtL D.C., was insufficient. While students uniformly reported enjoying many or most of these conversations, they felt like significant gaps were left in terms of some basic learning (e.g., more opportunities to learn about the specifics of Canadian policy making), skills development (e.g., those abilities necessary to interact fruitfully in a day-to-day policy setting), other methods of learning from guest experts (e.g., lectures, tutorials, and debates), and more regular and structured opportunities for critical reflection on speaker comments. The students also urged a better inclusion of different learning styles, beyond just informal conversation. Moreover, several remarked wishing that the faculty took a more active role in steering guest speaker conversations to use their expertise to guide the discussion to fruitful, controversial, or particularly salient topics.

## 6. Conclusions and Future Directions

The next generation of graduating engineers and scientists face a world where there are strong incentives and imperatives to work on complex topics of social relevance, to be able to translate their work to a policy and decision-making context, and to continually think in terms of broader impacts and public impacts. To do this effectively, and to engage with an ever-changing policy environment, students need to be trained on the subjects of policy, decision-making, and effective engagement with public experts and institutions. The SOtL program represents an attempt to do that with a unique program and format; an effort that we believe is worth significantly further development and evaluation.

The quantitative results from the programs in both Canada and D.C. indeed suggest that there are pre/post variations on participants, many of which could hint at a more nuanced and developed understanding of the interface between science, engineering, and policy. We highlight these results to emphasize that the point of SOtL programming is *not* to lambast science and engineering—participants continue to believe in the need for science and engineering in society, the value of this work, and the need for experts in society. What is open to broader consideration, in programs like SOtL, is the openness, humility, and reflexivity of participants in *how* science and engineering relate to society. Yet, it is difficult within this data to determine the particular ways in which each individual is making meaning of these changes, and whether they are empowering or discouraging future engagement with policy. Further research is important to assess this, and particularly to rigorously and robustly evaluate the learning impacts of the program.

The transnational comparisons are also intriguing. From experience running the program in both countries, it is clear that there is a distinct culture of policy and science policy in Canada versus the United States. Whether shaped by bilingualism, particular geographical or cultural differences, or the distinct historical trajectories of each country, the implication is clear: educational programs cannot be neatly transposed from the United States into Canada without significant adaptation. In particular, the Canadian student feedback on the D.C.-influenced program was striking, with a desire for much more significant and thorough instruction about policy and decision making, increased opportunities for critical reflection and discussion of the views presented, and for a wider variety of pedagogical styles and techniques.

For SOtL North, the first iteration led to a provisional set of refined learning objectives for the next year's program based on both areas of success and critical student comments. Once further developed and finessed, these student learning objectives should also provide a robust and more specific foundation for critical evaluation of the program outcomes. In SOtL North, students will:

1. Gain a better understanding of the basics of policy & science policy; improve their communication skills (e.g., communicating their research, asking good questions, and writing in policy-related genres); and increase their confidence in engaging with policy issues and Ottawa.
2. Develop networks with the policy community, increase their confidence in following up with these connections, and have an expanded sense of opportunities for them to participate in policy.

3. Understand and appreciate the real-world practice of policy making, as opposed to idealized/theoretical models.

Developing non-traditional education programs at the science, engineering, and policy interface is a difficult challenge. Models cannot be neatly transferred from one context to another, as the SOtL D.C. model had to be adapted on the fly in order to be suitable for a Canadian context. This adaptation is only just beginning, and will grow more substantive during the 2017 program. Yet, to ensure that engineering and natural science students are well equipped for the challenges ahead, it is evermore important to continue developing and improving such programs.

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# Transdisciplinarity Action Research workshop for sustainable technology communities

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## Abstract

The Research Institute for Sustainability Science and Technology under the Master degree in Sustainability Science and Technology organises the course Action Research Workshop on Science and Technology for Sustainability (5 ECTS). The authors have been coordinating the course during the academic years 13/14, 14/15 and 15/16. The purpose of the workshop is to put together civil society organisations, local administrations, students and educators to collaboratively undertake responsible research, using transdisciplinary Action-Research methodologies, to answer questions such as: Who are we researching for? Who profits from our research? What are the impacts of our research? Which methodologies and tools should be used? While dealing with socio-technological sustainability challenges.

Students work on real projects, related to local sustainability problems, represented by a community entity (Service learning and Campus Lab). Action research methodology is used with a two-cycle approach. In each real-life project, students, faculty and stakeholders are asked to follow the Action-Reflexion process of action research projects.

After three editions, we can conclude that: First, students realized the significance of framing an investigation under a research methodology that allows bringing research to the community, enhancing transdisciplinarity in any initiative or action. They set out the importance of some topics and the difficulty to hold them. Second, the formulation of the problem became one of the most arduous tasks in the process; difficulties were mainly related to the perception of the problem from distinct community group motivations. Third, interaction and communication with stakeholders and the recognition of their role was problematic because, usually, engineering students are not train to work in wicked problems and to work with stakeholders during the whole process. Finally, it is relevant to highlight that during the process students faced conflict and frustration situations, within their team and with stakeholders. To face that, an Emotional Intelligence module was introduced in the workshop and helped students to solve some paralyzing situations, which could have stopped the progress of the project. Hence, we suggest that engineering students need specific training in transdisciplinary research and conflict resolution, otherwise they could collapse in frustration when dealing with real transdisciplinary sustainability transitions.

## 1 Introduction

Sustainability issues are widely recognized as wicked problems (Yearworth, 2016), which should not be considered as problems to be solved, but as conditions to be governed. There is a general agreement on the need to reform scientific expertise, as it is required to deal with sustainability challenges, by developing new ways of knowledge production and decision-making. In that sense, Stephen Sterling

(2005) maintains that the nature of sustainability requires a fundamental change of epistemology, and therefore, of education. In relation to technological education, the Barcelona Declaration (2004) approved during the Engineering Education in Sustainable Development conference in 2004 declares the competences that engineers may have when graduating related to sustainability.

The Universitat Politècnica de Catalunya (UPC Barcelona Tech), aware of the new competences that engineers should have, offers a master degree in Sustainability Science and Technology. Within the Master, there is the course *Action Research Workshop on Sustainability Science and Technologies*. Next sections explain the learning environment and the challenges and lessons learnt when organizing such a course, as well as the learning results obtained by students.

## 2 Action Research Workshop on Sustainability Science and Technologies Course

The Action Research Workshop on Sustainability Science and Technologies is a course within the Master of Sustainability Science and Technology offered by Barcelona Tech University. It is a 5 ECTS (European Credit transfer System) course, which uses constructive and community oriented learning which has shown to be the most efficient way to train students in sustainability competences (Segalas, 2006; Segalas et al., 2010).

### *2.1 Goals and learning outcomes*

The purpose of the workshop is to put together civil society organisations, local administrations, students and educators to collaboratively undertake responsible research, using transdisciplinary Action-Research methodologies, to answer questions such as: *Who are we researching for? Who profits from our research? What are the impacts of our research? Which methodologies and tools should be used?* While dealing with socio-technological sustainability challenges.

When finishing the course students should have the next competences.

- To know and understand the research paradigms (positivist, interpretive, critical theory and pragmatism) on which the research theories, methodology, and methods are based.
- To be able to choose the most suitable research paradigm to tackle a real sustainability challenge.
- To be able to work in transdisciplinary research settings.
- To know, understand and be able to apply the action research methodology and research tools (quantitative and qualitative) in real-life contexts.
- Understand how their work interacts with society and the environment, locally and globally, in order to identify potential challenges, risks and impacts
- To reflect in the results of the research process and the research process itself in order to understand the social dynamics that appear when applying action research in real sustainability challenges

### *2.2 Course organization*

The course is organized around five areas (Fig. 1): Research paradigms, Action research methodologies, Dimensions of Action Research, Research tools and Reals projects.

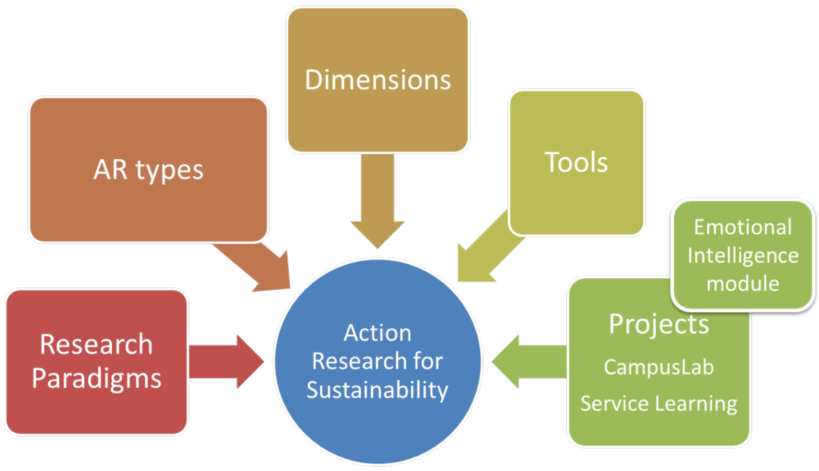


Figure 1: Workshop in Action Research structure

First students are faced with different research paradigms (Table 1) and its features in order to facilitate their reflection on the research that they should apply in their work as researchers. This is necessary because most of the students come from technological education holding a bachelor or master degree in engineering or architecture, and they usually only have been working with the positivist research paradigm which, when working with sustainability challenges with embedded social issues, is not usually the most appropriated (Martens, 2006).

Next, students are trained in Action Research methodologies. Starting with definitions (Wallace, 1987, Edwards & Talbot, 2014; Carr and Kemmis, 2009) and its main features (Whitehead & McNiff, 2002; Noffke, 2009) which can be sum up as:

- all the participants have something to contribute and to learn
- participants as co-researchers and co-learners, including the researcher
- knowledge and theory are inseparable from practice
- the main purpose is the improvement of a real situation or problem
- reflection and action are two core elements
- the whole learning-by-doing process is what counts

Once students are familiar with the main characteristics of action research, they learn about the main types of action research: i) Participatory action research (Baum et al., 2006); ii) Action learning (Revans, 2011; Kember, 2000); iii) Critical action research (Tripp, 1990) and iv) Collaborative inquiry (Coughlan and Coghlan, 2011). Students study their main features, pros and cons, methodological approaches and examples.

Table 1: Four scientific paradigms. (Sobh and Perry, 2005)

| | Paradigm | | | |
|---|---|---|---|---|
| Element | Positivism | Constructivism | Critical theory | Realism |
| Ontology | Reality is real and apprehensible | Multiple local and specific "constructed" realities | "Virtual" reality shaped by social, economic, ethnic, political, cultural, and gender values, crystallised over time | Reality is "real" but only imperfectly and probabilistically apprehensible and so triangulation from many sources is required to try to know it |
| Epistemology | Findings true – researcher is objective by viewing reality through a "one-way mirror" | Crating finding – researcher is a "passionate participant" within the world being investigated | Value mediated findings – researcher is a "transformative intellectual" who changes the social world within which participants live | Findings probably true – researcher is value-aware and needs to triangulate any perceptions he or she is collecting |
| Common methodologies | Mostly concerns with a testing of theory. Thus mainly quantitative, methods such as: survey, experiments, and verification of hypotheses | In-depth unstructured interviews, participant observation, action research, and grounded theory research | Action research and participant observation | Mainly qualitative methods such as case studies and convergent interviews |

Then, students are introduced to the three dimensions of action research (Noffke, 2009): Personal (practitioner as researcher and the process of self-reflection, planning and introducing changes to improve self-practice), professional (professional development purposes, to enhance profession) and political (generate democratic processes to empower groups lead to social change). These are overlapping and may be present in any action research study. These conceptualizations of action research allow students to position themselves as researchers when tackling a sustainability challenge in terms of research paradigm that may guide their inquiry, action research methodology that best fits the porpoise of their research and underlying assumptions on the dimensions of their research practice. Finally, students are trained in qualitative, quantitative and mixed research tools and methods typically used in action research: Conceptual maps, questionnaires, interviews, backcasting, complexity and network analysis, etc. At this point students are ready to apply the action research methodology (Fig. 2), following the action research loop of analysing-planning-acting-evaluating-reflecting in three cycles in order to frame the problem, intervene and evaluate the intervention.

They apply all their learning on Action Research in real sustainability projects under two active learning paradigms: Campus lab (Evans et al., 2015) and Service Learning (Sipos et al., 2008). Next section describes the projects that have been carried out during the three years of life of the course.

## 2.3 Three years of training

The course was born from convergence of two former courses: *Interdisciplinary workshop* and *Sustainable Technology Innovation* (STI) seminar, which used constructive and community oriented learning. In the Interdisciplinary workshop, its relationship with "real-life projects" was identified as a very powerful aspect, but methodological basis was missing. Moreover, STI clearly showed its enormous potential to bring social needs to the world of ideas, beyond a learning space. STI had also a strong methodology aspect, appreciated by students. In this sense, both needs were clustered to perform a course that deepen into research methodologies, with a strong transdisciplinary approach, to work real-life projects, with a sustainability perspective.

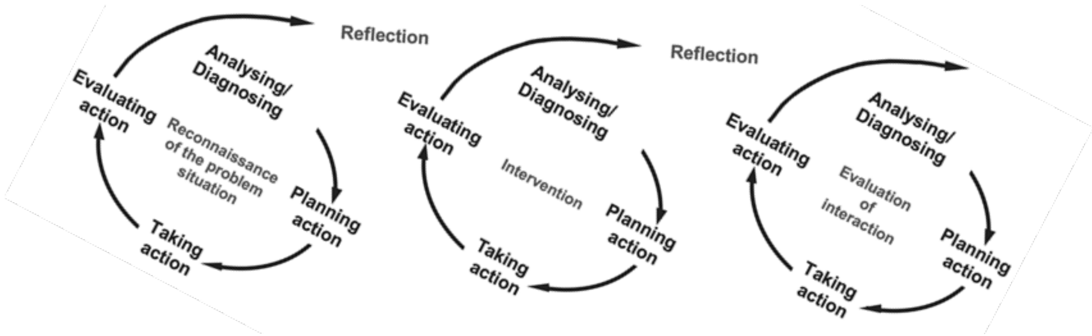


Figure 2: Action research cycles (Adapted from Coghlan and Brannick, 2014)

The course is organized around current sustainability relevant topics, broadly related to unsustainability aspects which are analysed in study real-life projects in local real situations, needs or challenges. Table 2 shows the topics for each course, organisations who lead their own real-life projects and the research question for each of them.

Organisations are called for collaboration and they bring their current demands to be developed jointly by teams of students, professionals, faculty and researchers. Participating organisations come from the UPC itself and from civil society and collaboration has been performed under Campus Lab and Service Learning respectively. The Campus Lab methodology is used because university as living labs can provide a potential holistic and iterative framework for the co-production of knowledge (Evans et al., 2015). Service learning is use as it is considered a strategy for action to achieve social transformation through education (Aramburuzabala, 2013). Real-life projects are constructed with the aim to both respond organisation requirements and enable students training and competence achievement.

Moreover, in order to increase transdisciplinary approaches we include in the course senior citizens thorough "*Aprendre amb la Gent Gran* (Learning with elderly)": a social program for the elderly, of the *Districte de Sarrià* (Barcelona). The aim of the program is to bring together and to establish linkages between all the stakeholders and seniors. During 6 to 8 sessions, the elderly worked together with students in the co-elaboration of academic works (surveys, reports, videos, diffusion pamphlets…). Students have learnt about personal strategies to address issues of awareness, (i.e. how to relate to groups that do have experiential knowledge, which may be far from a scientific-technical one); to listen at the experience of people and to have strategies to frame problems for people to understand, feel affected and own those "global" problems. Table 2 shows a characterization and the main features of the real-life projects. All the real-life projects has been guided by a research question, posed to pull the thread of the investigation and agreed by all the participants, which has been one of the most challenging stages in the Action Research process.

Table 2: Summary of the research projects process, research tools used and results

| Topic | Stakeholder | Real-life projects | Research question | Research tools | Results |
|---|---|---|---|---|---|
| 2014 | | | | | |
| Sustainable clothing and slow fashion | Clean Clothes Campaign (SL) | Spanish fashion in Morocco | What a local clothing company can do to minimize labour exploitation risk, when pushed to find suppliers in Morocco? | Literature review, surveys | Backasting report |
| | Slow Fashion Spain (SL) | A local booming sustainable clothing market | What are the barriers and challenges faced by sustainable fashion initiatives in current markets? | Literature review, surveys | Backasting report |
| 2015 | | | | | |
| Energy poverty in Catalonia | Energy Bank Association (EB) - Municipalities Premià/Sabadell (SL) | Detection of motivations to participate in the EB in Premià | What are the factors that influence the decision to join the driver group of EB? | Surveys, interview | Clusters analysis |
| | | Phase 1 of implementation of the Energy Bank in Sabadell | What key factors that encouraged real participation in a local energy program can be used for EB? | Surveys, | Report on online poll |
| Energy inefficiency in public buildings-UPC | Office of Sustainability OGSIO- UPC Energy Optimisation Projects (EOP) (CLab) | Analysis of communication networks in the performance of EOPs structure | Does the current organizational structure of the EOPs, influence on the obtained results? | Surveys, interview | Report on Network Analysis |
| | | Reporting server "orphan building" (*) energy consumption | What part of servers' consumption can be attributed to information management and which to use? How to reduce their energy consumption? | Surveys, interview | Report |
| 2016 | | | | | |
| Energy poverty in Catalonia | Energy Bank – Premià (SL) | Phase 2 of EB implementation in Premià: private sector | What affordable and sustainable offer could facilitate the priate organizations involvement to the Energy Bank? | Focus groups | Strategy approach design |
| Gas Geopolitics | OdG- Debt Observatory in Globalization (SL) | MIDCAT, huge construction of a mega- pipeline for gas interconnection France-Spain | What is the capacity of this civil organized campaign facing to maximize transparency and public accountability? | Data analysis, surveys | Policy paper |
| | | Gas imports of the Port of Barcelona | What is the city responsibility on the perpetuation of fuel energy model based on natural gas? | Data analysis, surveys | Policy paper |
| *Communities for energy* performance | UPC Energia 2020 (CLab) | Energy Hackathon design for developing sustainable energy projects at UPC | What kind of activity should be proposed to increase community participation in sustainable energy systems at campus? | Focus groups, interviews, pilot | Guide: 1st UPC Energy Hackaton |
| UPC's water management teaching | EWB- Engineers Without Borders (SL) | What kind of water management is promoted at UPC? | Does UPC Water education and research respond to need of ensuring the human right to water? | Surveys, interview, network analiss | Mapping of relationships |

(*) This "Orphan building" is where the UPC servers are located. High consumption of servers masks the efforts of energy saving, causing no one feels responsible for energy optimization

*SL -Service Learning; CLab- Campus Lab*

### *2.4 Course Assessment*

The assessment in the course is design to evaluate, the learning of the students and the course itself.

At the end of the course, students have to deliver two reports. A first report where they analyse all the Action Research process that they have applied reflecting on: the research paradigms, Action Research types and its dimensions, research tools used, Action Research cycles applied and the results obtained. A second report is the result of their research to be delivered to the "client" (guide, policy paper, communication strategy, etc.). Those reports are shown in an oral defence to all the stakeholders and clients, student mates and faculty. Faculty assesses the Action Research report using a rubric (Craig, 2009), the rubric is also used by the students in the peer-assessment (Topping, 1998). Moreover stakeholders/clients evaluate the results provided by the students.

In order to evaluate the course, two explicit reflexive questions are asked to the students: *What have I learned in this course?* And, *What do I think about the course (structure, organization, timing, projects, etc.)?* The results of the students' reflexions have been clustered in table 3.

Table 3: Reflections of students about their learning and the course

| | Topic | Relevant comments from students |
|---|---|---|
| Learning | Research methodologies | • *Qualitative and Quantitative approaches are needed to see beyond the numbers.*<br>• *I learned the relevance of qualitative aspects as we learned more from direct interaction with people than with quantitative data obtained by "R software".*<br>• *The management of relations with qualitative research, which is not usually taught in tech universities, have been very stimulating*<br>• *Qualitative data from interviews is a very inspiring process* |
| | Stakeholders | • *I have learned the relevance of stakeholders and the role they play.*<br>• *To realise that the different needs and concerns of stakeholders may shake the project process.* |
| | Transdisciplinarity | • *We learn to work with people from different disciplines and to improve our communication skills when working with professionals with different project management schemes*<br>• *We learn to be more tolerant with our group mates that have different background and ways of working.*<br>• *The most valuable point was the interaction with stakeholders from other disciplines, listening their points of view and experiences in the topic.* |
| Course | Real-life projects | • *To participate in a real project has been very interesting and being in touch with real stakeholders*<br>• *I liked to work in real projects* |
| | Discussions in class | • *Which I liked the most was the organization and group work in class, allowing to listening and learning from each other* |
| | Low directedness | • *There were many expectations at the beginning from all stakeholders and we feel a bit lost*<br>• *The goal of the research had to be defined between the stakeholders which delayed the project, and was time consuming*<br>• *The planning was confused and it took time to our self-organization with the stakeholders*<br>• *I think that this course give us too much freedom to make our choices, depending on the stakeholders and the goal were changing…* |
| | Comprehensive project | • *The course should be run at the first semester as a course that uses the knowledge of the other courses that we take simultaneously in a comprehensive real-live project.*<br>• *It will be interesting to integrate more than one course in a project like this, so we will have more time to perform a better project.* |

In relation to the learning process, most students appreciate: i. learning with mixed research methodologies and tools; ii. dealing with stakeholders' interest and their relevant role in sustainability challenges; iii. the need of Transdisciplinary approaches; and iv. teambuilding. In relation to the course, they appreciate: i. the real-life projects both Service learning and Campus Lab with real stakeholders/clients; ii. the group work sessions in the classroom with interesting discussions and reflexions on the project process. The main criticisms were related to the low degree of directedness at the beginning that for some was very frustrating, (the low directedness was deliberate in order to train students in dealing with stakeholders' different interests in real settings). Due to the frustration among students, the course coordinators introduced an emotional intelligence workshop in the course (see next section). Another issue for improvement is that students feel overwhelmed with project work as this course is run simultaneously with other 6 courses and most of them have project work. Students suggested that there should be a comprehensive project for the whole semester where each course can contribute from its theme. This suggestion is taking seriously by the master coordination unit and we are now redefining the master structure.

### *2.5 Emotional Intelligence module*

As commented before students longed for some capacity to bring back the "energy of frustration" related to the project uncertainty and to be able to give a positive approach to obtain a final result, "having patience" to develop and obtain results. At the same time they claimed for strengthening the group's relationship as necessary to feel comfortable in a work dynamics which demands more participation, better communication and somehow to get out of the self comfort zone. Students realized that as professionals they should face situations in which have to: manage emotions; solve unexpected situations; solve frustrating situations in the workplace; and of course, manage teams. We decided to offer a different approach to their understanding, posing that many times this kind of situations may be approached by means of generating situations of empathy to ensure that participants can relax and create new common codes. The module aims to allow students obtaining some experiential knowledge related to emotional intelligence and what are the related competences. These interpersonal competences, related to emotional intelligence are rarely included in curricula, although they have been widely studied and claimed (previuos works: Kunnanatt, 2004; Barth et al., 2014; Dlouha and Burandt, 2015). Regarding the structure of the module (session of 2,5h), it starts with a framing theoretical introduction about emotional intelligence (see Gardner, 2001; Bisquerra, 2007), multiple intelligences theory (Mayer & Salovey, 1997; Goleman, 1996) and related competences, always in the framework of sustainability (Lambrechts et al., 2013; Wiek, 2011). Then students experience some dynamics of therapeutic theatre. The module follows the thread of the 5 domains of emotional competence: *emotional awareness, emotional regulation, emotional autonomy, social competence, skills for life and well-being*, proposed by GROP[1]. After an initial group distension dynamic, the module is conducted, through dramatized exercises.

Participants recognize in an experiential way what are the emotions involved in each of the domains of emotional intelligence, self-competence in all of them and, also, how emotions can be perceived, expressed, understood, regulated and facilitated. Furthermore, one of the students contributed as reflection that "*I considered as an great enjoyment not only to find out how a group dynamic is working, also to see himself acting as an individual integrated in a wider sense, but also to learn about its own consciousness and capacity of nonverbal communication and awareness*".

[1] GROP: Psychopedagogical Counseling Research Group. MIDE, Faculty of Education. University of Barcelona. http://www.ub.edu/grop/

## 3 Conclusions

After the three editions, we can conclude that: First, students realized the significance of framing an investigation under a research methodology that allows bringing research to the community, enhancing transdisciplinarity in any initiative or action. They set out the importance of some topics and the difficulty to hold them. Second, the formulation of the problem became one of the most arduous tasks in the process; difficulties were mainly related to the perception of the problem from distinct community group motivations. Third, interaction and communication with stakeholders and the recognition of their role was problematic because, usually, engineering students are not train to work in wicked problems and to work with stakeholders during the whole process. Finally, it is relevant to highlight that during the process students faced conflict and frustration situations, within their team and with stakeholders. To face that, an Emotional Intelligence module was introduced in the workshop and helped students to solve some paralyzing situations, which could have stopped the progress of the project. Therefore we suggest that engineering students need specific training in transdisciplinary research and conflict resolution, otherwise they could collapse in frustration when dealing with real transdisciplinary sustainability transitions.

The participation of the senior learning program *Aprendre amb la Gent Gran*, has provided a perspective of intergenerational and interpersonal skills, and the relationship with the elderly has provided values and communication and interpersonal skills to students.

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# Propagating an Integral and Transdisciplinary Approach to Sustainability Education


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## Abstract

Recent directions in engineering for sustainable development (EESD) (and in ESD more generally) have pointed towards an increasing realisation that in order to adequately begin to address respective meta-problems associated with global (un)sustainability, 'object world' disciplinary perspectives *alone* are insufficient. Instead, the required depth of knowledge that expert disciplinary knowledge can provide must be both complimented and built upon by other disciplinary as well as experiential knowledge. Integral and transdisciplinary approaches to learning can play a central role in helping achieve this.

When such approaches are applied, they facilitate the possibility of new and emergent knowledge and insights which can transcend disciplinary bounds, with the potential to reach places where no single disciplinary approach can; a classic case of 'whole greater than the sum of parts'. This however requires a degree of disciplinary humility and openness to other approaches and disciplinary norms, as well as a degree of trust, patience and time. Nevertheless, in the context of seeking authentic sustainability, it is necessary.

The classical engineering degree structure is not amenable to this approach. Engineering has traditionally seen itself as a 'problem solving profession only insofar as 'problems', including complex socio-technological ones (with ecological and economic import) can be neatly reduced to well-defined closed system decontextualized 'puzzles' which can then be algorithmically optimised. This is deeply problematic as it cannot map reality; specifically, complex contemporary 21$^{st}$ century reality, instead resulting in emergent 'unintended consequences'.

A key intervention point therefore in the development of a fit-for-purpose cohort of engineering graduates capable of addressing emergent twenty first century meta-problems is through their formative education. Here integral and transdisciplinary approaches to sustainability education/ESD offer a useful approach. But this requires not just the inclusion of 'sustainable development material', but a perpendicular reconceptualization of pedagogical approaches. This approach coheres with contemporary pedagogical best practice as it privileges relational and constructivist approaches to learning over the traditional atomistic approach, incorporating as it does, peer to peer and personal reflective learning opportunities.

This paper reflects on the experiences of a programme where undergraduate chemical engineering students undertaking a sustainability module collaborate with students on an analogous sociology module. It describes how this transdisciplinary collaboration takes an integral approach to sustainability learning, incorporating both subjective and objective perspectives as well as inter-subjective and inter-objective. The work reflects on how this initiative worked by drawing on student feedback and the authors' experiences.

## 1 Introduction

Disciplinary engineering knowledge is invaluable in addressing the inter-connected 'grand challenges' that are increasingly present through contemporary twenty first century society. These challenges, which incorporate nexus issues around energy, water, food, ecological degradation and climate change, as well as human societal issues around health, increasing inequality and ethics, may all be considered as emergent symptoms of 'unsustainability' across an increasingly global(ised) society (Ehrenfeld, 2009; Byrne, 2014; Fitzpatrick *at al.*, 2015)). When framed in this way, 'sustainability' can be characterised as an emergent property of a (flourishing) complex system (Ehrenfeld, 2009). The dominant contemporary paradigm, which is a paradigm of reduction and disjunction (separation) is by this conception considered unfit for purpose (Morin, 2008). This has deep implications for the self-perception the expert engineering professional and for their role in problem solving. The traditional conception of the engineer (that is, subject to a paradigm of separation, and hence silo-isation with respect to other disciplines) allows that all problems can be reduced (as per a paradigm of reduction) to linear decontextualized 'puzzles' capable of being 'solved' through suitable algorithmic means, invariably through some sort of technological intervention (Bucciarelli, 1994; Buch & Bucciarelli, 2013; Byrne & Mullally, 2014). However, irreducibly complex problems require a recognition of their complex and deeply interconnected nature. This means that the 'object world' of the expert professional, while being crucial in addressing any such problems, is at the same time, by itself, insufficient.

By this paradigm of reduction and separation, the issue of climate change for example can be considered as a problem from the perspective of the engineer which can ultimately be 'solved' primarily by the development and application of appropriate technological interventions (such as for example, technologies to harness renewable energy forms). However, by the same token, from the perspective of the lawyer equally it becomes a problem to be solved through a global legal framework. This same problem to the economist is one which can be resolved by appropriately incorporating economic externalities, while from the perspective of the political scientist it is a problem of political will or structure. A social scientist may see the problem in terms of how humans relate to each other through stories, myths or (meta-)narratives, or in terms of structure and agency and/or may recognise it as ultimately an issue of ethics and normativity. Each disciplinary perspective thus offers its own unique and privileged 'solution' to the same problem from their own disciplinary silo-ised 'object world' view of the world around them.

If we take an alternative worldview through the lens of a paradigm of complexity however, all the above respective perspectives are each envisaged to offer some truth and value in terms of both framing and addressing the issue(s) at hand, but such a paradigm also recognises that no one disciplinary perspective can offer a complete or definitive characterisation or response. Instead, the integration of all these perspectives, and *more*, is required. We say *more*, because such an integral and transdisciplinary perspective would also recognise the value that the experiential knowledge (knowledge in addition to that of the expert) can bring to the problem, for example, local, community and coalface experience, while for intricate complex problems like those of climate change, there is also a recognition that there is a deep interconnection between this symptomatic issue and other problems of unsustainability including food, energy, water, as well as those residing in broader environmental, economic, ethical, political and social domains (Byrne, 2014; Byrne et al., 2016).

## 2 Background and rationale

It is with this understanding that engineers not only require a toolbox which provides them with the expert disciplinary knowledge that will enable them to address emerging contemporary meta-problems around unsustainability, but that they will also have to go beyond that by recognising that it is only through working with other disciplines as well as those with experiential and local knowledge that we can collectively begin to adequately both frame and address these issues. It is founded on the realisation that what may have been considered adequate in the training and practice of the professional engineer through its most recent manifestation through the latter part of the nineteenth century and through the twentieth century, is now no longer fit for purpose, if it ever was. Indeed, much of the real and perceived progress over this past century and a half, fuelled as it was by a splurge in (almost literally) free energy in the shape of a fossil fuelled bonanza, has been a perfect complement to a socio-economic model based on growth based consumption (and consumerism). This has had severe downsides, most obviously manifest in the ecological domain, but also in the social, economic and ethical domains. Put simply, it is the second law manifestation of the fact that there is no such thing as a free lunch; 'if there is a foundation on which all environmental degradation rests, it is entropy generated by the ever-increasing transformation of energy by humans' (Wessels, 2006, p.51).

This realisation that what is required is a 'new engineer' (Beder, 1999) or the conception of the engineering professional one who is 'committed to a social good and being structured (constrained in various ways, privileged in others) so as to achieve that social good. …In this conception of a profession, and only in this conception, can we understand engineering as a morally worthy enterprise, worthy, that is, of individual commitment and social recognition.' (Bucciarelli, 2008, citing Johnson 1989), entails that the self-perception of the engineer must be broadened beyond the narrow confines of the 'guns-for-hire' model, to one which incorporates and embraces the reality of socio-economic and macro-ethical dimensions in professional training and practice (Conlon & Zandvoort, 2014).

The implication of this, to the authors, as academics grappling with issues around (un)sustainability and how these might be reflected in the disciplinary education of our respective students was pretty clear. If we demanded that engineers have a broader conception of their role while recognising the inherent complexity and interconnectedness when faced with contemporary meta-problems, then their formative educational experience would need to go *beyond* the (absolutely necessary disciplinary) requirement for development of the technical and disciplinary basics which facilitates the solving of well-defined decontextualized unique solution technical problems. If we are to expect contemporary engineers to work with *other* disciplines and *integrate* respective knowledges in the generation of requisite new knowledge and perspectives to frame and address contemporary meta-problems, then we couldn't really expect them to achieve these aims by merely 'talking the talk' and then hoping that they would do so post-graduation, all the while educating them in a parallel formative education system.

This was the motivation behind the initiative between the co-authors of this paper, as academics respectively in engineering and sociology, who taught on respective third year modules to our students on 'Sustainability in Process Engineering' and on 'Sociology of the Environment'. The result was a part bringing together of these modules for a common group assignment whereby students were tasked with identifying one aspect of 'sustainability' which interested them and which they were then asked to both frame and characterise, while also offering their perspectives through a coherent group presentation followed by a short individual reflection piece.

The motivation here was to, in a spirit of transdisciplinarity to open the possibility (and legitimacy) for undergraduate students of both engineering and sociology (the latter module was taken by students taking both sociology and government degrees) to frame and seek potential useful intervention points with respect to aspects of societal (un)sustainability. Furthermore, it was also intended to do this by applying an integral approach to learning, as one which seemed ideal for facilitating productive reflective learning in particular around complexity and associated wicked problems.

## 3 An Integral Approach for Sustainability Education

### *3.1 Assignment Description*

A common assignment was designed for two third modules which ran concurrently at University College Cork: PE3011 Sustainability in Process Engineering (taken by students in the third year of a four year Bachelor of Engineering degree in Chemical Engineering) and SC3029 Sociology of the Environment (a module taken by third year students of the Bachelor of Arts degree, majoring in sociology and other humanities subjects as well as a BSc in Government). A number of international visiting students also took the module (from the European mainland, the USA and Brazil). The assignment, which is worth 15 percent of the overall module grade for both modules (10 percent for the group presentation plus five percent for the individual reflection), has run successfully since 2014 (Byrne & Mullally, 2016). The work associated with this paper is drawn from the 2015-16 iteration when a total of 42 students undertook the module including 26 from the engineering module. The students were divided into ten groups of four or five each, split between the two modules, and each group were tasked with choosing a topic or aspect of their choosing relating to some aspect of ‘sustainability’. The following represents part of the task description presented to the students:

> *The task involves transdisciplinary teams of four or five working together to consider some aspect of sustainability. This will be done through the context of your own respective modules as well as bringing to bear your own object world disciplinary (and personal) perspectives and backgrounds. The resultant product may involve contrasting perspectives, framings or angles on the topic at hand or it may result in an emergent creative fusion of differing object worlds and disciplinary norms. Any aspect may be chosen by the group that relates to ‘sustainability’ to research and then reflect upon. The group reflection is open ended and can be directed as you best see fit. For example, you might like to consider what this aspect or topic means (to yourselves or to society), how it has the* ***potential to change the way we/you do things****, consider* ***how it can or might be achieved****, what are its* ***potential consequences****,* ***difficulties*** *or* ***problematic issues****, why or how it is so powerful a* ***concept****, and so on.*

Once groups had settled on a common theme, they were required to discuss it with a member of the lecturing team, who provided feedback and suggestions to the respective teams. The lecturing team during 2015-16 included the authors of this paper, plus a colleague on the sociology module Dr Kieran Damery.

### *3.2 Application of an integral model*

During the 2015-16 iteration, an integral model was purposely chosen in structuring and delivering the joint sustainability assignment. Integral approaches cohere well with both transdisciplinary and sustainability imperatives as they recognise different levels of realities within the whole while rejecting a totalizing unity in favour of what might be called *‘unitas multiplex’* (Morin, 2008) or ‘unity amidst diversity and diversity through the unity’ (Klein, 2004). This model was developed following integral approaches to education (Esbjèorn-Hargens *et al.*, 2010), in particular as described in the application of mathematics for teaching by Renert & Davis (2010). This model is a four quadrant model which incorporates in turn the following domains:

- Subjective (personal understandings of reality as filtered through/constructed by personal lens of each individual)
- Objective domain (the material, facts, meanings and disciplinary interpretations, meanings and norms)
- Inter-Subjective (emergent collective/cultural understandings, including socio-cultural norms)
- Inter-Objective (structural framework/nature of the module/assignment, including clas times/duration, location(s), assessment, delivery mode(s), number and make up of participants, lecturer(s))

The ongoing development and incorporation of its associated sessions were informed by this model, as outlined in Table 1.

Table 1 Incorporation of an integral approach to learning/teaching for sustainability assignment

| Domain: | How it was facilitated: |
|---|---|
| Subjective | Post module personal reflection by each student highlighting personal learning gained from the exercise. |
| Objective | In-class content, including viewing of a documentary looking at conceptions of progress in contemporary globalised society, including the examination of environmental, social, economic and ethical dimensions. Material on assignment description, as well as complimentary module material (handouts, slides, required reading, etc.). |
| Inter-Subjective | Collective in-class discussions stimulated and structured by lecturing team, both after documentary (acting as stimulus and 'ice-breaker') and around the group exercise. |
| Inter-Objective | Structural context, including a designated 1 hour session over 5 consecutive weeks in a designated room as well as assignment (requirements, grades) and delivery structure (designed to facilitate each of the other domains). |

Taking the integral model as a lens for considering the assignment and its delivery, the following key aspects were considered as key in helping to address all four domains of the model respectively;

The structure of the assignment (**inter-objective**): This was an important aspect of the joint assignment which the authors had to consider as it needed to facilitate the addressing of each of the other three domains. There were also structural constraints relating to timetabling (student and staff), and type and availability of room. The sessions were carried out over one hour during five consecutive weeks followed by a presentation session where each of the ten groups made a presentation to their peers and the lecturing team on their chosen aspect of sustainability. It was decided to incorporate a kick-off documentary over the first two weeks [objective] in order to stimulate discussion around a common focal point. These were characterised as initial 'Workshop and Group Brainstorming/Preparation Sessions'. This in turn fed/led into the prescribed group assignment where groups were charged with agreeing to consider/research/frame/propose interventions on some aspect of sustainability about which they would develop and deliver their respective presentations [objective]. Apart from the documentary, the remaining session time was heavily skewed towards the facilitation of in-class group discussions [inter-subjective]. Finally, individual participants were required as part of the assessment the deliver a short reflection after the delivery of the group presentations [subjective].

The 'priming' documentary (**objective**): The documentary was shown in two parts over the first two sessions and was the principal piece of material in this collaboration (module specific material was delivered separately as part of each of the respective modules). It was followed during each session by a group discussion which considered a broad question (e.g. on what participants considered as the relationship between progress and sustainability). The documentary thus acted as a useful common focal point for all participants doing this exercise, while it was broad enough to address sustainability aspects under all principal domains, including ecological, socio-technical, economic and ethical. It also proved to be a useful learning experience for participants, while the shared experience helped to make it act as an ice-breaker for participants with different disciplinary 'languages' (and cultural) backgrounds who also did not know each other heretofore.

The in-class group discussions (**inter-subjective**): These provided an opportunity for students to converse across each other's respective disciplinary languages, and to help students better appreciate the different 'object worldviews' that students from other disciplines held, and indeed more fundamentally, to appreciate that students from different disciplines legitimately held different 'object worldviews'. This could raise potentially difficult challenges for the students, even in terms of framing a problem with respect to some commonly chosen aspect of sustainability. It thus played a critical role in the assignment and the students' associated learning (as evidenced by student feedback, see later).

The reflective piece (**subjective**): students were required to each write a short reflection (of 400-600 words) on how they thought the transdisciplinary assignment worked and what they felt they learned from the exercise after the completion of the group exercises.

### *3.3 Student output*

The groups appeared to work very well together, and came up with a range of topics related to sustainability, which they presented at the final session. These are listed in Table 2.

Table 2: Sustainability related topics chosen by groups for presentation

| Group | Chosen 'sustainability' topic | Group | Chosen 'sustainability' topic |
|---|---|---|---|
| A | Sustainability and Ethics | F | Globalization and Inequality |
| B | Waste | G | Homogeneity & Diversity |
| C | Industry and Sustainability | H | Defining Progress |
| D | Inaction and Sustainability | I | Awareness & Behaviour |
| E | Entropy | J | Consumption & Consumerism |

The presentations were each of eight minutes duration and were given by all members of the group, followed by a short question and answer session. While the presentations worked well, it was the personal reflections of the engineering students which appeared to demonstrate most ably how they had learned from and developed their thinking around sustainability challenges as a result of their experience of the assignment, while it also revealed some of the more difficult issues around the exercise. One student's reflective assessment is indicative:

> *As an assignment I felt it was interesting to engage with a different discipline than engineering; something we did not have an opportunity to do for the first three years of the degree. The main benefit of this was the different viewpoints and experiences that the sociology students were able to bring to the conversation. The Erasmus exchange student was able to provide insights into how the topic of sustainability is evolving in Denmark; something we could only speculate about. Their cultural attitude was also evident as they seemed to*

*value environmental conservation at a level greater than that of the Irish. However, there were a number of drawbacks to this joint assignment; in particular, the government student failed to properly engage with the subject of sustainability. Instead he opted for a business as usual approach where he suggested that we should continue to research into the subject. The lack of a sense of urgency in his approach was frustrating and seemed more like a means of maintaining the current global paradigm. Therein lays the problem however; that sustainability means different things to individuals and may be the reason why real change is so difficult to implement.*

## 4 Student feedback

Student feedback was collated through a bespoke survey that the authors put together which aimed to see specifically how the integral approach to module pedagogy worked through a series of questions which mapped each of the four quadrants of the integral model onto aspects of the assignment. 32 out of a possible 42 students completed at least part of this survey (a 76% response rate) including at least 22 (out of a possible 26) PE3011 students (85%) (three did not indicate which module they were taking). The results are presented in Table 3 with cumulative average (Avg) and standard deviations (S.D.) included. In terms of the integral model, questions 1 and 2 were designed to elicit feedback on subjective aspects of the assignment, while the remaining questions were aimed at determining how students' conceived that the inter-objective, inter-subjective and objective domains worked respectively. Feedback was pretty unanimously positive across all domains, in particular (and encouragingly for the authors) with respect to the inter-subjective domain of peer-to-peer and group engagement, where over 90% of respondents awarded either a four or a five.

Table 3 Aggregated quantitative student feedback on joint sustainability modules

| *In relation to both **your module (PE3011/SC3029) and the accompanying assignments:*** | **Worst** | | | | **Best** | **Avg** | **S.D.** |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | | |
| 1. How did they help you ***personally*** engage with and reflect on issues around sustainability? | - | 1 | 6 | 13 | 12 | 4.13 | 0.83 |
| 2. How did they help ***you*** develop a ***deeper understanding*** of issues around sustainability? | - | 1 | 5 | 14 | 12 | 4.16 | 0.81 |
| 3. How well was the module ***structured*** in a way (lectures, delivery, videos, interactive sessions, etc.) that facilitated engagement and learning around the relevant issues? | - | - | 10 | 12 | 10 | 4.00 | 0.80 |
| 4. How well did the module facilitate ***peer to peer*** and ***group*** engagement and learning? | - | - | 3 | 18 | 11 | 4.24 | 0.62 |
| 5. How well did the ***material*** presented (notes, slides, videos, etc.) facilitate engagement and learning around the relevant issues? | - | 1 | 6 | 12 | 12 | 4.13 | 0.85 |

The positive response was borne out by the responses to an additional two qualitative open ended questions which dealt with what students felt were 'particularly useful' aspects of the exercise and how it 'might be improved' respectively. The responses here cohered with the positive feedback generally; on the improvement question only structural issues (inter-objective) came to the fore e.g.

the tiered room used was not most conducive to good group interaction, the duration of the presentations could be longer and there could be a better balance between student numbers from respective module. In terms of particularly useful aspects, quite a number of students mentioned the documentary as being a useful lead in focal point/stimulus (objective), while the remaining comments dwelt principally on the value of the group/discussion components (inter-subjective) as well to a lesser extent the opportunity to personally reflect on (and hence re-imagine) sustainability conceptions (subjective). Selected indicative responses reflecting these latter domains are displayed in Table 4.

Table 4 Qualitative student feedback on joint sustainability modules

| Can you highlight any aspects of the module or its delivery that you found ***particularly useful?*** |
|---|
| *Hearing others opinions and further discussing them* [Inter-Subjective] |
| *It was very good to discuss the topics amongst the class. It feeds more 'real' to open a dialogue rather than be fed research done by others.* [Inter-Subjective] |
| *Helps give a deeper understanding by giving different perspectives and looking at topics from different points of view.* [Inter-Subjective] |
| *Allowing students to give their opinion – debating* [Inter-Subjective] |
| *The aspect I found most useful was the greater understanding I obtained of "true" sustainability'. Not the sustainability model that has been marketed to us of continued consumption but in a greener way. This module clearly outlined the problem with this model of growth and has made me more conscious.* [Subjective] |

## 5 Conclusion

A four quadrant integral model was imposed upon and used to assist in the development of a transdisciplinary exercise around exploring meta-problems around sustainability for engineering students working with on a joint exercise social sciences students. From the perspective of the authors, the application of this model proved appear to be particularly useful in informing the teaching of sustainability, though ultimately the exercise appeared to work very well in stimulating productive dialogue and shared understandings across disciplinary boundaries. Moreover, formal student feedback showed the student learning experience to be overwhelmingly positive. While it highlighted some (relatively fixable) shortcomings in structural delivery (inter-objective), students felt that other domains of the integral model were very well covered, in particular the inter-subjective domain which was addressed through designed opportunities for peer-to-peer, lecturer-student and intra-class dialogue and discussion.

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# What Do We Know About EESD and How Do We Know It?

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**Abstract**

Huckle (2004) has argued that critical realism (CR) can provide a philosophical framework for higher education for sustainability. This paper reflects on the process of researching EESD in the Irish context and the usefulness of our approach which used mixed methods and drew on CR as its guiding philosophy. We will argue that aspects of the CR approach: its emphasis on a depth ontology, the search for causal mechanisms, its model of agency/structure relations and its emphasis on the combination of extensive and intensive methods provide tools for exploring EESD as a system. CR requires us to focus on "deeper things" in the examination of the integration of SD in engineering education. This leads to an argument for the requirement for deeper change to facilitate the development of a social model of engineering education which more fully embraces all dimensions of SD.

## 1 Introduction

Huckle (2004) has argued that Critical Realism (CR) can provide a philosophical framework for higher education for sustainability by providing a philosophy of knowledge "that integrates the natural and social sciences and the humanities...supports critical pedagogy, and continues to regards education as a form of enlightenment linked to a vision of more sustainable futures" (34). His argument is based on the depth ontology of CR and its potential to provide an ontological grounding for interdisciplinary approaches to (SD) and education for sustainable development (EESD). This depth ontology encourages us to look beyond the surface appearance of things to uncover their generative causes. In this paper our focus is on how CR impacts research design and how we used the logic of CR to examine engineering education for sustainable development (EESD) in a limited number of programmes in three institutions in Ireland. Some results of different phases of this work have been reported previously (Nicolaou and Conlon 2012, 2013, 2015, Nicolaou, Conlon and Bowe 2015). In this paper we seek to integrate the findings and provide an account of how our approach was influenced by CR.

## 2 Critical Realism

CR has emerged as an alternative paradigm in the social sciences to positivism and interpretivism. It combines a realist ontology with an interpretive epistemology. A key feature then of CR is the distinction between the, intransitive (the world which is the object of our knowledge) and transitive (our knowledge about the world) domains. CR argues for the primacy of ontology and also that the nature of what exists cannot be unrelated to how it is studied (Archer 1995). In seeking to explain phenomena CR offers a distinctive approach.It offers a depth ontology: a notion of a stratified reality which includes a distinction between the domain of the real (generative mechanisms), the actual (events) and the empirical (experiences). Structures of objects at the level of the real generate mechanisms that facilitate events. They are not observable but their effects are felt nonetheless. They can be inferred through empirical investigation and theory construction. Realist explanations consist of connecting experience in the empirical domain with structures and processes in the real domain. This is potentially emancipatory in that it forces us to consider “that certain states of affairs cannot be ameliorated within existing structures” (Collier 1994: 10). They must be changed.

A feature of this depth ontology is the linking of the natural and social worlds. The biological world is emergent from the physical and the social from both. As a consequence social science needs to be combined with natural science to understand how society is embedded in nature, while natural science needs to be combined with social science to understand the form that nature takes in particular social circumstances (Huckle, 2004). While arguing that the social can be studied scientifically critical realists also argue there are differences between the natural and social sciences. Firstly, taking the conduct of experiments as a starting point CR argues that the kind of closure offered by laboratory experiments is not achievable in the real world. Therefore causal mechanisms must be studied as part of open systems where their effects may be blocked by the operation of other mechanisms (Robson, 2011). Thus their impact is conditioned by the context in which they operate. Realist seek to show how it is that in the particular situation in which research is taking place “there was a particular configuration involving a set of mechanisms that had the particular pattern of results achieved” (Robson, 2011:37).

Secondly, social structures are maintained through the activity of people. CR offers a particular social ontology focused on the relationship between structure and agency. It is committed to an explanatory model “in which the interplay between pre-existent structures, possessing causal powers…and people possessing causal powers…of their own results in contingent yet explicable outcomes” (Carter and New 2004: 6). CR is committed to *analytical dualism* in that structure and agency are seen as objects of a radically different type possessing different properties and powers (Carter and New 2004). Thus CR acknowledges the value of interpretivist methodologies which focus on discourses, beliefs, motivations and meanings as human reasons (or as Carter and New call them “psychological mechanisms”) can serve as causal explanations. They are critical though of interpretivists who fail to relate these to underlying social structures which may enable or constrain action. On this account social and cultural structures are seen to be causally efficacious. The tranformative potential inherent in human agency can only “begin to bite when structural contexts ...are generally supportive of those potentialities being actualised in some durable form.” (Reed 2005:302).

## 3 CR and Research Design

CR acts as a general orientation to research practice. In arguing for its usefulness in research design, Robson (2011) highlights some of the features of CR discussed above: “First. A general issue. Research very commonly seeks to provide explanations. Answers to ‘how’ or ‘why’ questions – how or why did something happen? Realism addresses these issues directly, providing a helpful language for this task. Secondly…(t)his is that virtually all real world research takes place in a ‘field’, rather than laboratory situations. Realism provides a way of approaching such open, uncontrolled situations” (Robson 2011: 30). He also points out that particular features of the CR ontology are useful in providing an ontological justification for using mixed methods. This is significant in light of his claim that those who use mixed methods need to explain their design but also have “the additional task of clarifying and making explicit your rationale” for mixing methods (2011: 168).

A full discussion of the latter issue is beyond the scope of this paper other than to point to the importance of different research paradigms in providing researchers with ways of thinking about which kinds of research questions are important and what constitutes answers to these questions (Robson 2011). Many researchers rely on pragmatism to justify their use of mixed methods allowing the research questions to dictate their methods. While CR is sympathetic to this position the problem is that there is always an implicit or explicit conception of the nature of reality which generates particular research questions. Further if you "presuppose that social science studies are conducted in an open system but nevertheless study the phenomenon using quantitative methods, which require a closed system, you must be very observant about what conclusion can be drawn" (Danermark *et al.*, 2002: 152). Thus attention must be paid to the connection between ontology and methods.

CR is not committed to any particular methods but rather argue for the use of "critical methodological pluralism" (Danermark *et al.*, 2002). Given their rejection of the ontologies underpinning qualitative and quantitative methods critical realist prefer to talk about combining extensive and intensive methods given their different roles in identifying mechanisms and how they manifest themselves in different contexts. Mixed methods are necessary to reveal different features of the same layered reality and offer a robust option for uncovering generative mechanisms while also identifying which phenomena occur most frequently (Hurrell, 2014). As reality is stratified data collected at the empirical level can shed light on the operation of mechanisms. Extensive methods need to be complemented by intensive methods focused on processes and *how* a mechanism works in a concrete situation.

While some are critical of CR for being overly focused on theory (for example Robson 2011, who describes his approach as 'realism-lite'), research based on CR tends to be conceptual. Given its focus on unobservable generative mechanisms it tends to seek to provide theoretical explanations of the social world and generalise about theoretical propositions. In doing research CR tends to emphasise the importance of abstraction, abduction and retroduction.

Since social systems are open it is very difficult to examine their structures in controlled conditions (Sayer, 2000). CR's logic of abstraction allows researchers to conceptualise the components of an open system and investigate each component's influence on the system in isolation. Abstraction encourages the development of conceptual frameworks which identify what is significant in examining the phenomena under investigation. Critical realists use two distinct explanatory logics in moving from the empirical to the real: abduction and retroduction. The former describes the observed in an abstracted or more general sense in order to describe the sequence of causation that gives rise to regularities in the pattern of events, while the latter seeks to ascertain what the wider context must be like in order for the mechanisms we observe to be as they are (O'Mahoney & Vincent, 2014). Retroduction is a mode of analysis in which events are studied with respect to what may have, must have or could have caused them: "In explaining associations they seek to distinguish what must be the case from what merely can be the case" (Sayer, 2000: 27). Having set out some key features of CR the remainder of this paper will discuss how this general orientation influenced our research.

## 4 Research question and conceptual framework

Our initial research goals were focused on understanding the integration of ESD in engineering education in Ireland. Influenced by CR and the absence of research on the Irish situation we needed to first establish the pattern of integration by collecting and analysing empirical data. But we also wanted to explore the causal mechanisms which might explain the pattern of integration. In order to do so it was decided to focus on a small number of programmes (7) in a small number of institutions (3) of different types. Four of the programmes were in one institution. The other three were in similar and different disciplines in the other two. This would allow us to gather both extensive and intensive data on a small number of cases and also allow us to consider whether the disciplinary and institutional context was significant in shaping the pattern of integration.

The data collected was based, firstly, on a student survey (with 371 respondents in either their final or first year). This built on Carew & Mitchell (2002) and Azapagic *et al*., (2005) and mainly asked students to rate their knowledge of a variety of SD principles, tools, issues and policies but also asked them to describe SD, sought to establish their commitment to SD and sought their opinions on issue related to strong and weak sustainability. Secondly, programme documents were analysed (296 separate modules were examined) to identify coverage of learning outcomes for SD as set out in the Barcelona Declaration (BD) and SD competencies as identified in the literature (e.g.Wiek *et al.,* 2011). Finally, interviews with the seven programmes chairs/leaders were conducted. They were designed to explore their views of SD and the integration of the concept in their programmes, as well as their views about the factors that impact programme design. An interview was also conducted with a representative of the accreditation body for professional engineers (RAB from here).

The first two provided considerable data which allowed us to extensively map the pattern of integration while the latter allowed us to intensively explore what shaped this pattern of integration. When the project was initially conceived the plan was to conduct a survey of staff but this was abandoned, in favour of in-depth interviews with programme chairs,, given the need to explore in greater depth what the underlying mechanisms might be: “Qualitative methods can help to illuminate complex concepts and relationships that are unlikely to be captured by predetermined response categories” (Mc Evoy & Richards 2006: 71). We needed to move from the empirical to the real and retroductively explore the mechanisms that explain the pattern of EESD.

In doing all of this we were clearly influenced by the literature and the conceptual and theoretical issues that arose from it and its identification of various factors which influence the integration of ESD. Given the limitations of space here it is not possible to cover all the issues[1] other than to say that a CR lens encouraged us to adopt a systems approach to ESD (Sterling 2004). There was a desire to maintain a focus on the system as a whole and interaction of different mechanism while at the same time ensuring that both the descriptive and explanatory gaols of the project were met. There was a concern to maintain a focus on the interrelationships between the different aspects of the phenomena.

In light of this a conceptual framework (See Fig 1) was used to guide the research process in moving from the descriptive to the explanatory. It summarises the research landscape regarding EESD. At the top the focus is on the empirical dimensions of EESD: students’ knowledge and the curriculum[2]. These can be evaluated in light of learning outcomes and competencies which have been identified as necessary for SD (the latter can be seen as ideal types which allow for the evaluation of concrete instances). At the bottom there are three interacting dimensions: professional accreditation process and the professional culture; academic and organisational cultures and lectures knowledge of and beliefs about SD. These dimensions have been identified as having an important influence on EESD and as such represent explanatory mechanism which would need to be explored in the course of this project. When drawing this up we were more conscious of the need to abstract out the key elements of EESD rather than hypothesise any particular pattern of causality at that stage.

[1] Most of the key issues are identified in Ashford (2004), Boyle (2004) and Mulder et al. (2012).
[2] While issues to do with teaching methods were examined as part of the project the focus in this paper is on programme content.

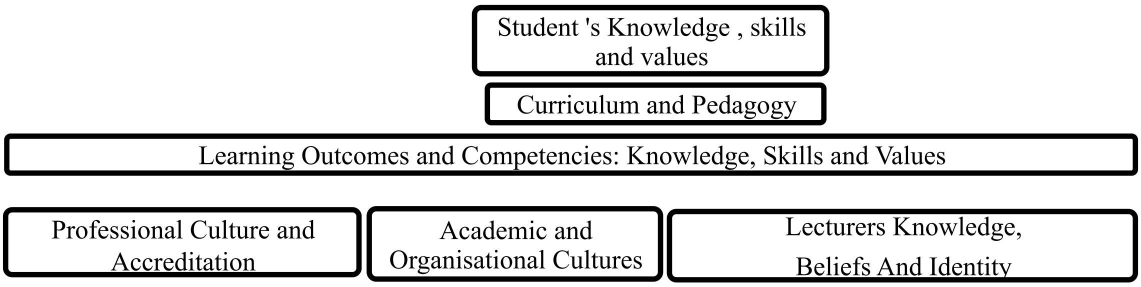


**Figure 1 Conceptual Framework**

## 5 What do we know?

As most of the data has been presented previously, what follows is a short summary of the data gathered using extensive methods followed by a discussion of the mechanisms identified from the interviews with programme chairs. The data from the extensive phase of the project are presented in Tables 1 and 2.

Table 1: Summary Results of Student Survey

| |
|---|
| Final year students rate their knowledge somewhere between “Heard but could not explain” and “Have some knowledge” (2.49 on a scale of 1 to 4). First year students average score was 2.24. |
| They rate their knowledge better in relation to environmental issues and tools |
| They do not report the same degree of knowledge about social issues (equity, social inclusion and public participation) and legislation and policy |
| Final year students’ descriptions of SD are focused on the environmental dimension. Less than 10% mentioned the social dimension in their descriptions. |
| Final year students tend to focus on one dimension when describing SD. Those who see it as multidimensional describe it as an environmental and economic concept. |
| When final year students’ self-reported data were compared with new entry students’ data it was found that there are similarities regarding their perceptions of their knowledge Differences were identified on issues, such as energy, resource management and environmental protection, directly related with final year students’ discipline. |
| There was evidence that to suggest that students’ knowledge of the social dimension did not differ significantly from new entry students’ self-reported level of knowledge. |
| Students’ self-reported knowledge is significantly related to their programme of study. |
| Final year students agree that the environment should be protected but not at any cost. |
| They are more likely to see SD as a professional requirement rather than a personal commitment |

Whilst perhaps unsurprising, there is a clear alignment between both sets of data. The evidence would suggest a fragmented, rather than a holistic, approach to SD. While students say they have some knowledge of important components of SD their knowledge is focused on the environmental dimension including the use of resources. The focus is on those aspects of SD close to the disciplinary core of the different programmes. While some modules can be seen to be addressing outcomes for SD, they do not specifically address SD in their learning outcomes or content descriptions. Others have content relevant for SD but no reference to SD in their outcomes. The focus tends to be on delivering engineering fundamentals though a consideration of issues such as energy and environmental protection. When issues related to SD are addressed in modules they are often not linked to wider discourses linked to SD. This is also the case for many of the modules which focus on skills development. They are not contextualised by the need, for example, to foster stakeholder engagement or public participation in decision making about technology. Rather the focus is mainly on improving the communication and teamwork skills of students in the context of improving their employability.

Table 2: Summary Results of Curriculum Investigation

| |
|---|
| Programmes' overall focus is on transferable skills (such as communication) development over knowledge and values for SD. While there is some evidence for the development of critical thinking, the higher domain (evaluation) of critical thinking is developed to a lesser extent. |
| Programmes from Institution 1 focus on skills while programmes from Institutions 2 and 3 focus more on knowledge for SD |
| Modules that deliver content for SD focus on the environmental aspect of the concept |
| Regardless of the degree the programmes focus on elements from two BD outcomes which address engineers' social and environmental obligations and the need to keep abreast with SD technologies. In relation the former the emphasis is on their environmental obligations. |
| The social dimension of SD is not evident in the programmes. Only one module addressed the issue of stakeholder participation in its learning outcomes. Only four addressed the BD outcome focused on understanding their work in different cultural and political contexts. |
| It is not evident how commitment to SD values is generated in the programmes. Modules that focus on ethics focus on micro ethical issues and professional responsibilities as set out on the code of ethics |
| The knowledge that is delivered for SD is related to each discipline. Hence, based on the discipline different elements of knowledge about principles, legislation, tools and issues are covered |
| There is very little evidence of inter or multidisciplinarity in the programmes |

This disciplinary focus, which is reinforced by students having very little exposure to teachers who are not engineers, especially in the later stages of their programmes, is creating an unbalanced approach to the integration of the three dimension of SD. Analysis using Arsat *et al's*. (2011) framework shows that only four modules across the institutions are consensual: they address all three dimensions of SD. In summary it can be suggested that the focus is on "generating disciplinary knowledge and developing skills". The Barcelona Declaration specifically cautions against such an approach. The general approach, regardless of institute type and discipline, has the character of what Sterling (2004) calls a "bolt-on" approach "of sustainability ideas to existing systems, which itself remains largely unchanged". Optimistically he notes that this is "much better than nothing, and can open the door to deeper change" (59).

We wanted to explore deeper issues in the interviews with programme chairs. We wanted to raise a number of issues which had arisen from the previous stages of the project. But we also wanted to explore these issues in light of key factors that arose in the literature which were deemed to have an effect on programme design. Using abduction and retroduction we wanted to "add theory to data" (O Mahoney & Vincent 2014). We wanted to encourage reflection on what the key factors shaping programme design were and how they might be constraining the implementation of EESD in the programmes. The data was analysed using thematic analysis with an iterative analysis leading to the identification of key latent themes which focused on the professional identity of the respondents and their philosophy of engineering education and, within that, their views about SD. Some key findings are:

- All of them had an engineering focused education and significant industrial experience: SD was not a part of their engineering education;
- The majority of the programme chairs the describe SD as a concept that relates economic
- development with environmental considerations that are mainly focused on energy, materials and resource issues. Only one described it as a three pillar concept;
- Their views about SD lead to a generally positive assessment of its integration in their programmes;
- There is a strong disciplinary focus on core engineering competencies in programme design; when asked to discuss any particular focus on content for SD, the majority of them identify elements directly related to the discipline of each programme;

- They agree, when prompted, that the social dimension is not well integrated: although ethics were identified as an important characteristic of engineers who want to contribute to SD, these were limited to engineers' professional conduct in relation to materials, safety and the environment while the social context of their practice was identified to a lesser extent;
- SD is not an active consideration in programme design;
- Concern about professional accreditation was identified as the most significant influence on programme design;
- All of them value the autonomy they enjoy in designing their programmes and oppose the imposition of an institutional policy for EESD;
- The majority of the programme chairs argue strongly that the role of their programmes is to educate employable graduates that will have the competencies needed to work in industrial environments which include some elements related to SD.

It is quite clear (and RAB agrees) that SD is not a key driver in programme design. Indeed he suggests that perhaps SD is not necessarily a concern for all engineers: "If there was a programme that's in the sustainable area or the renewable resources we would get experts in that space and focus on that particular area during accreditation". According to him "discipline specifics" are dealt with most and there would be a danger that "sustainability is involved now but in five years time it might be something else". The accreditation criteria do not explicitly mention SD but rather "responsibilities towards people and the environment". While Irish EESD may lack a "bold legitimising catalyst for sustainability related curriculum development" (Jones *et.al* 2010) the real issue is what that says about the underlying approach to education.

In a manner not dissimilar to critical realism Sterling (2004) analyses higher education using an iceberg metaphor and argues that "the deeper levels of paradigm and purpose guiding policy and practice...tend to be hidden from view and...most debate"(64). In terms of purpose the chairs support an emphasis on core engineering competences which is supported by accreditation processes which emphasise the development of employable graduates for industry. While their responses show that the integration does not follow a multi-disciplinary approach and a neglect of the social dimension, the programme chairs say that they do not see any weaknesses in the way their programmes deal with SD. Only one programme chair was critical about how SD is treated. Their descriptions of the concept suggest that the majority of them see SD as a *guarding concept* that is based on a sense of techno-optimism and traditional engineering practice focused on guarding exploitable resources, waste minimisation and environmental protection and supports a disciplinary emphasis in knowledge for SD (Carew and Mitchell, 2006). This allows them to claim that SD is adequately addressed. Seeing themselves as members of the industry which they serve, as well as of their professional body, leads to them espousing a set of values which endorses an employability agenda as a criterion of the effectiveness of their programmes. In the main they were satisfied that their programmes met the goals for which they were designed.

The structure of engineering education, based as it is on disciplinary based programmes and schools and their own experience of education reinforces their commitment to disciplinary education. This is reinforced by a strong commitment to academic autonomy. This has the effect of reinforcing their professional identities as engineers as they are resistant to the idea of an institutional policy to guide the integration of SD, but yet had no difficulty with a policy emanating from their professional body. It appears that the autonomy they value is from non-engineers. This may be a block to institutional initiatives aimed at developing interdisciplinary engagement. At a deeper level the approach of the chairs is dominated by a commitment to a model/paradigm of engineering education located somewhere between the science and market driven approaches as identified by Jamison (2013). As part of this the see SD as mainly a technical issue focused on environmental and energy related issues with little attention to the social dimension. In CR terms there are a set of reinforcing mechanisms facilitating the provision of disciplinary education aimed at producing technically proficient, employable graduates in which the social dimension is marginalized.

## 6 Conclusion

Jamison's (2013) typology of engineering education is useful in that it emanates from a concern to educate "green engineers" and links specific views about engineering education to different engineering identities and views about what it means to be an engineer and therefore what the goals of engineering education should be. In arguing for a socially driven model and the creation of hybrid identities for engineers, he is seeking to build on the CR insight regarding the intertwining of the natural and social worlds and the need to understand both in addressing unsustainability. This implies "in context" learning and a commitment to interdisciplinarity.

He is also pointing to the need to focus on "deeper things" in fostering educational change. In moving towards this goal the research reported helps us understand why approaches focused on policy and practices (particularly those of individual lecturers) are likely to fail. While we can see that there is some engagement with SD and evidence that some issues are being addressed our use of CR has helped us to identify some of the locks (mechanisms) which are preventing the door being opened to deeper change. Without engagement with the culture and structures that maintain and support current practices deeper change is unlikely to occur and be sustained.

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# Can teaching sustainability principles guide engineering design?

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## Abstract

This paper explores whether adopting clear sustainability principles at the outset of an engineering project can define a creative design space from which radical and novel engineering solutions can emerge, in contrast to simply designing to meet the traditional constraints of quality, cost and time.

Reference is made to a number of core principles (such as polluter pays, precautionary principle, the Natural Step, social principles, biomimicry principles, life cycle thinking and cross cutting principles such as advocated in the Earth Charter, the Hanover principles, CERES Principles and Equator Principles.) Many of these reflect eco-design notions which are key in underpinning the circular economy . A series of 4 Absolute Principles, 12 Operational Principles and 2 Personal Principles will be introduced which can be applied to infrastructure projects at all stages of project delivery ( from developing a business strategy through project scoping, stakeholder engagement, procurement, outline and detailed design, construction and in-use to end of life decommissioning) .

Finally a Masters level module called *Sustainable Design and Implementation* is described, which asks students to propose technical solutions to a set of issues (identified by them) which face emerging mega-cities and to develop these within the boundaries and constraints defined by an appropriately chosen set of sustainability principles. The module has run as part of Cambridge University's MPhil in Engineering for Sustainable Development for the last 4 years, and the nature of the student responses to these tasks will be examined and critically reviewed.

## 1 Introduction

Engineering design is a creative process but constrained by physical laws and natural limits. Central to engineering education is to convey the concepts of physical principles, such as conservation of mass or Newton's laws of motion. They provide the rules, ideas and boundaries that must be kept in mind when solving an engineering problem. They ensure the engineering design will work and is fit for purpose. Designers also adopt principles to help guide their thinking, from "keep it simple stupid" to "keep the target user in mind". They help provide a touchstone against which a proposed design or engineering solution can be tested. Traditionally an engineering project is judged against three overarching principles: that it is of the right quality, it has been delivered within a specified budget and it has been completed on time to a defined programme of work.

Engineers are therefore completely familiar with the notion that working within such critical principles bound and steer their work. This paper extends this process and argues that adopting clear sustainability principles at the outset of an engineering project can define a creative design space from which radical and novel engineering solutions can emerge. Coupled to this approach is the educational benefit engineering students can experience by robustly examining whether framing an engineering problem in this way leads to a radically different solution than would have emerged from more traditional approaches.

### *1.1 The nature of principles*

A starting point has to be determining which principles apply in the context specific circumstances that a solution has to be delivered. Many sustainability principles have been suggested and there are ongoing debates, and sometimes esoteric arguments, surrounding the focus that different principles choose to emphasise: "deep green" or "light green", weak or strong sustainability, ethics and/or economics. Their history and a philsophical perspective is given by Simon Dresner (2008) and they have been usefully reviewed and summarised by Edwards (2005), who sees strong similarities in the values these principles express. He summarises the recurrent themes which they embody as:

1 Stewardship
2 Respect for Limits
3 Interdependance
4 Economic restructuring
5 Fair distribution
6 Intergenerational perspective
7. Nature as a model and teacher

Edwards points out that such principles play a key role in setting the context for the choices that organisations make, and that while some focus strictly on values, others include a defined methodology or standard for implementation. If these can be attached to key sustainability themes, they can be used to help guide sustainable decision making at all stages of engineering design and project delivery and should be central to the educational formation of all engineers.

## 2 Sustainability in Engineering Design

Muldur (2016) sees engineers as the experts that design and operate the main metabolic systems of an industrial society. He argues that choices lock technologies into specific pathways of development and these choices cannot be undone over time – perhaps locking out, for example, renewable technologies. Choice is at the heart of engineering design, for example in the selection of materials, the scale of the solution, the access and availability to potential users, the opportunities for re-use and so on. Design work should better connect these choices to the main challenges of society.

More specifically, ensuring that the natural resources required to manufacture the products and services needed by society are utilised in in a way that preserves their availability for future generations is a key challenge for process and product design (Seay (2015)). Key drivers connected to product design are global energy utilisation, societal and intergenerational equity, climate change and population growth. Seay recognises that consumers are widening the criteria they use to make purchasing decisions beyond simply cost and quality concerns, such that process design decisions relating to end of life issues and material sourcing must be addressed. He notes that a key principle of design must now include the entire product life cycle and that the ability to quantify uncertainty will be a key skill for design engineers and must be included in any sustainable design process. These skills must be provided through education so that engineers avoid green washing and the unintended spread of incorrect or misleading information on the impacts of a product or servie. Working within the guidelines (and boundaries) provided by appropriately chosen sustainability principles is a key way this can achieved and design decision making justified and defended. Furthermore such an approach can open creative doors as innovation and novelty are stimulated.

An integral approach to sustainable design has been proposed by Pereira (2009) which adopts the principle of whole systems analysis, where solutions are not designed as single plug-in fixes to existing systems, leaving unsustainable structures untouched and in place. This is driven by the principles of being autonomous, self sufficient, self-regenerating, completely independent of distant resources and fossil fuel. Similarly Bakshi (2014) commenting on methods and tools for sustainable process design points to the principle that sustainable designs do not exceed nature's capacity to provide the needed ecosystem goods and services.

From a chemical engineering perspective Charpentier (2016) provides a good example of how adopting a principle such as green chemistry generates constraints which require an integrated system approach of complex multidisciplinary, non-linear, non equilibrium processes and transport phenomena occurring on different time and length scales of the chemical supply chain. Thus a process designed and engineered based on green chemistry principles for the customized product design, will commercially be "green" only if scaled up correctly, which will lead to the development of cleaner new green (sustainable) processes.

The classic design and manufacture model is well described by Johnson and Gibson (2104) as a linear process moving from the Client Brief through Concept and Detailed Design to Manufacture. Applying the principle of minimising resource use and life cycle impacts extends this sequence so the designer considers post manufacture phases of how the product performs in use, the impact of its maintenance and the means of final disposal. Adopting the principle of the circular economy adds further refinement to how an initial design might be approached where waste can simply be defined as a failure of design. This can require designers to develop ways of recycling a product, making sure it has a longer in-life use, cascading its final disposal as a feedstock to other industries and ensuring its "technical nutrients" (McDonough and Braungart, 2013) can be easily dis-assembled and separated. These actions naturally follow once preliminary principles, such as those advocated by the Natural Step (Robert, 2002), have been adopted. Equally important are the development of metrics to track how designs are performing against these principles such as indicators of material circularity (Ellen MacArthur Foundation 2015).

The design process has been described by Bry Sarte (2010) as involving the following elements:

- Identifying and understanding the project drivers
- Setting goals
- Establishing desired outcomes and metrics for success
- Creating frameworks and action plans that organise this approach
- Identifying concrete, measurable design strategies to achieve the above factors

Teaching sustainability principles must lie at the heart of guiding these core decision. Birkeland (2005) echoed this view when commenting "Education in the 21st century, and particularly design education, will need to be of a new order that encourages "system design thinking" to achieve eco-solutions.

## 3. Choosing the relevant principles

One of the difficulties with many sustainability discussions however, is how to apply widely accepted principles in day to day practice. In other words how can the new engineering professionals operationalise what they have learnt from an academic environment. To address this directly Ainger and Fenner (2014) have proposed a hierarchy of sustainability principles that can be applied effectively at every stage of the project lifecycle. First there are 4 **absolute principles** which are incontrovertible consequences of natural science laws and basic humanity. They should sit alongside the familiar concepts of physical principles when solving an engineering problem. These absolute principles are at the heart of driving sustainability and represent ***the constraints*** within which engineering activity must be delivered.

The first two of these principles are defined by the planetary boundaries circumscribed by Raworth (2012). They refer to *A1: Work within environmental limits* imposed by the 9 planetary boundaries which must be preserved to maintain the essential natural support systems of the planet. Simultaneously *A2: Develop minimum socio-economic standards* for humanity by helping to provide the social foundation for development in terms of provision of minimum quantities of food, water and energy as well as the right to education, gender and social equality and employment.

The third principle: *A3: Consider intergenerational equity* simply requires that decisions and actions taken now don't close off options or choices for future generations to live sustainably. It asks engineers to take an anticipatory view of the kind of future they wish to create in ways that products and services can add benefit, and avoid damage into the future. While the engineered services that society enjoys have often provided buffers against environmental extremes (drought, flood, food security, disease transmission), they sometimes have done so at the cost of a lock-in to expensive technical solutions that do not respond well and cannot be adapted quickly, to the changing and uncertain circumstances which will be faced in this century. Bequeathing assets that lack the necessary resilience to respond to a range of plausible future scenarios is one way in which engineers have already constrained those who come after them.

The final absolute principle is *A4: Conceive solutions as part of a wider complex system.* In most civil engineering projects, for example, there are links between the technical aspects of transportation, building or water systems and social systems, based on the users of the infrastructure, as manifested in urbanisation, communication and public health, and also the environmental attributes of their natural and urban surroundings. These are intricately linked. There are flows of materials, wealth, energy, labour, waste and information between these systems. Better understanding of these inter-dependancies should reduce the unexpected consequences arising from narrow decisions taken in one infrastructure sector having adverse affects other sectors. As Paul Brown (2008), Executive Vice President of CDM (USA) has observed: "*to achieve sustainable urban development we need to do more than improve the efficiency of each of the component parts of our infrastructure – we need to do so at the level of the whole urban system*".

These absolute principles translate into a more workable set of operational principles which can help engineers set objectives and guide actions in day-to-day practice. They help establish a distinct way of doing things, partly by recognising issues that traditionally may not have been within the engineer's remit. They are ***the processes*** that need to be embraced at each stage of a project and include the following:

- Set targets and measure against environmental limits
- Structure business and projects sustainably
- Set targets and measure for socio-economic goals
- Respect people and human rights

- Plan for the long term
- Consider all life cycle stages
- Open up the problem space (beyond sectoral and discipline boundaries)
- Deal with uncertainty
- Consider integrated need (encouraging multi-functionality of assets)
- Integrate working roles and disciplines

Crucially it is as individuals, acting alone or collectively, that decisions are made that can influence a project outcome to be more sustainable. These represent the often overlooked ***value base*** for sustainability, reflecting both an individual's professional and personal ethos. Engineering students should be educated to ask a fundamental question of themselves at every stage of their careers: "Am I acting sustainably?". This requires embracing two final individual principles: *Learn new skills* and *challenge orthodoxy and encourage change.*

Ainger and Fenner (2014) show how these principles can be applied to infrastructure projects at all stages of project delivery, from developing a business strategy through project scoping, stakeholder engagement, procurement, outline and detailed design, construction and in-use to end of life decommissioning. In outline design this involves working in interdisciplinary teams, so that all interfaces are considered and reviewing the project scope so that sustainability is reflected in it, and if necessary widening the range of options considered to include real sustainable alternatives. In particular it is good practice to identify a benchmarked sustainability option (BSO) which is taken through to a final shortlist so that sustainable options are not eliminated during evaluation. In detailed design it is important to ensure all sustainability intentions carried through from previous stages are applied to the project detail and described using clear sustainability metrics. An important mindset here is to be prepared to challenge traditional approaches and design standards.

## 4 Sustainable Design and Implementation

### *4.1 Module Description*

For some years a module called " Sustainable Design and Implementation" available to students on Cambridge University's MPhil in Engineering for Sustainable Development for Sustainable Development has tried to grapple with the issues raised above. The starting point is to recognise that solutions often lie in the swamp of messy problem as a described by Schon (1987), being those that are not of technical elegance but of most pressing human concern.

A number of core principles are examined (such as Polluter Pays, Precautionary Principle, the Natural Step, social principles, biomimicry principles, life cycle thinking and cross cutting principles such as advocated in the Earth Charter, the Hanover principles, CERES Principles and Equator Principles.) The students are then introduced to concepts of sustainable design strategies, industrial ecology and the circular economy.

The module is delivered through a combination of academic sessions and contributions from invited practitioners and experts in the field of engineering design. Students are then asked to reflect on possible technical solutions to issues facing megacities. This exercise is intentionally open ended and non-prescriptive so the students have the freedom to define their own specification in relation to a mega-city they are familiar with or is relevant to them, and issues relating to an engineering area or activity which reflects their own backgrounds and engineering sectors

The students are expected to synthesise and draw on the module content and in so doing generate a diverse set of responses. The exercise is not framed explicitly around a detailed design but a more open ended technical appraisal which may be the starting point for such a design to emerge.

The assignment brief is described in Box 1.

Box 1: Assignment Brief

**What Technologies are Essential for Megacities of the Future to be Sustainable?**

Over half the global population lives in an urban environment. There are significant socio-economic promises which stimulate migration to the city. However, the urban impoverished suffer from poor housing, infrastructure and job prospects.

What technologies exist or are necessary for cities of the future to deliver social equity, environmental protection and economic prosperity to their poorest residents?

Make reference to appropriate sustainable principles you have followed in recommending specific solutions

Criteria by which the work will be assessed:

- Context and issues identified (framing the problem)
- Justified selection of relevant sustainability principles to guide and bound technology choices
- Review of sustainable technologies and their contribution (in the context you have identified) and how their choice is guided by the adopted sustainability principles
- General clarity of argument and logical structure
- Use of reference material

Note: responses should not be restricted solely to a technical description of a new technology but should reflect how a technology or technologies can be designed to satisfy explicit aspects of sustainability for an issue and location of your choice

( e.g water supply in Mmumbai, transport in Sao Paolo etc etc)

A key aim of the work is to explore how, beginning with a recognition of sustainability constraints and principles, the final solution to a problem may look rather different to what it otherwise might have been designed.

*4.2 Student performance*

In completing the work students frequently make use of a change matrix (Figure 1) which helps structure their response. This allows a mapping of whether solutions follow Pereira's description of plug-ins to existing systems (described earlier), or re-design to deliver the same service in new, novel and innovative ways, or to redefine the system boundary by changing to different models, institutional structures or wider technological options to meet the fundamental need. This year topics ranged from, amongst others, urban transport in Delhi, housing in Tokyo, integrated infrastructure provision in Cairo, water services in Dhaka, air pollution mitigation in Beijing, flooding in Lagos, flood mitigation in New York, and housing affordability in London.

Experience in running the module over the last 5 years has shown that in some cases student responses compartmentalise a number of good ideas and technologies rather than achieving an overall synthesis. Others go further and reflect also on the complexity of megacities and how this can create problems as well as sometimes creating emerging properties in the form of self-help coping strategies by those who live there. Whilst many clear solutions are presented which meet the sustainability principles adopted there is often less attention paid to examining the practicality or feasibility of adopting these in the specific context of the city chosen. Another drawback is that in some cases the discussion is pitched more at the national level rather than in the detailed constraints of a specific mega city.

Sharper responses focus on one technology or engineering service in one clearly defined geographic region. The exercise encourages students to review the business as usual approaches to the problem they have highlighted which reveals a number of unsustainable practices and thus helps provide a strong rationale for consideration of alternative solutions driven by the adoption of appropriate sustainability principles. A key learning outcome is the students identify and appreciate there a lot of constraints on their chosen system which must be addressed to deliver an effective solution that satisfies across multiple dimensions. This can lead to proposals for system innovation requiring significant institutional and organisational management for these to work, which questions and widens the nature of the design process.

| | Optimize | Re-design | System Renewal |
|---|---|---|---|
| **Technology** | e.g. Improve the efficiency of the Carnot engine.<br><br>Use lighter weight materials (composites instead of metals) | Use a hybrid electric or fuel cell system for energy<br><br>Change the shape of the car for improved aerodynamics | Provide access to desired goods and services without need for vehicular transportation, e.g through improve telecommunication |
| **Organization** | Improve the efficiency and safety of private public transport routes | Operate on demand calls for public transport<br>( e.g Wiggly bus) | Retain ownership of the cars and sell mobility as a service<br>e.g River Simple hydrogen cars |
| **Institution** | Congestion charging in urban centres | Integrated operation between transport modes, rail, bus, tube | Urban planning designs communities so commercial districts and employment are within walking distance |

Figure 1: Change matrix (with entries relating to urban transportation)

The exercise was well received in the recent student feedback for 2015-16, with comments such as: "*Being able to step back and truly think and analyse how the design of a large scale solution might impact a mega city now and in the future broke down many of the assumptions I would previously have made*" and " *The change matrix was great as it helps guide thinking that could otherwise feel haphazard and a 'stab in the dark' by giving categories and definition to the brainstorming process*". An analysis of the separate assessment categories for this year's group of 30 students taking the module reveals students performed almost equally well across all aspects of the assignment ( see assessment criteria in Box 1) , performing just marginally less well (by 1%) in how their technological choices were guided by their adopted sustainability principles than the other categories.

## 5 Conclusions

It is clear that using sustainability to bound a design problem is essential in guiding the choices that are taken at all stages of the design process, but moreover provides a way of engaging students in an approach which stimulates innovation and creativity.

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# Flipped classes and enriched skeleton maps to foster deep and interactive learning in engineering education

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## Abstract

This paper reports the initial experience of applying the enriched skeleton mapping technique as innovative and meaningful learning methods within a flipped class teaching setting. Driven by the low confidence and autonomy of many undergraduates; this study focus on stimulating collaboration and interactive learning. The study was performed in a course labeled 'sustainable building construction technology' of the Bachelor of Architectural Engineering program at Liege University (Ulg). First year and second year students, were assigned to an experimental group of 27 students and a control group of 8. In the experimental group, students worked together in pairs on mini-concepts and created enriched skeleton maps for the course content. The control group received a regular ex-cathedra course. The results show that students who used the enriched skeleton mapping technique were more engaged and outperformed the control group. Enriched skeleton concept mapping fostered deep learning and resulted in a better understanding of the course mini concepts in addition to the course structure and domain. Students of the enriched skeleton mapping found learning to be more 'useful, stimulating and more engaging', whereas students of the congenital ex-cathedra curriculum found learning to be 'passive and boring'. A combination of both techniques may provide the most effective training for undergraduate engineering students.

## 1 Introduction

We live in a challenging time where sustainability and circularity of economy are two foundational pillars. In this content knowledge and knowledge development are critical economic factors. Higher education graduates need a deep understanding of sustainability concept and principles and the ability to generate creative ideas, new theories, and new solutions in harmony with nature for a better future. Within the engineering education and particularly architectural engineering, there is a concern to link the teaching and research to the changing labor market. Through our teaching, we seek to train highly qualified students with hands-on knowledge and practical and analytical skills in order to be able to solve problems and to innovate. According to the League of European Research Universities (LERU) the future generation engineering students should be taught respecting the four following recommendations (Dale, 2007):

- New knowledge is the source of innovation;
- Skills are the major contributions in research;
- Knowledge of current market development is important for education;
- The need to integrate projects in education (not only theoretical instruction).

As new faculty member at the Faculty of Applied Sciences of the University of Liège, responsible of undergraduate sustainable building construction technology courses, we had a concern to find fit to purpose teaching methods allowing us to meet the above mentioned challenges of students born around the millennia known as iGeneration. We believe that the ex-cathedra classical teaching method thus proves to be insufficient to prepare our undergraduate students and equip them with experiences and skills on sustainability. The combination of ex-cathedra lectures, constant use of smart phones, tablets and laptops in class and the uncertainty of undergraduates about their study choice and future carrier during the first years turns many of them easily to passive learners. In order to face these challenges we tested the flipped class setting courses from 2014-2016 during courses for freshman architectural engineering students at Liege University in Belgium.

The flipped classroom is an instructional strategy and a type of blended learning that reverses the traditional learning environment by delivering instructional content, outside of the classroom. The flipped classes teaching method is not a new concept at the University of Liège. In his book "*Towards a pedagogical university teaching quality*", Leclercq introduced in (1998) the LQRT method which stands for home reading/questions and answers/testing. He associated this LQRT method with 11 principles that can be associated, even today, with flipped classes' method. This model gained recently a momentum in the University of Liège, which reformulated the relationship of outside classroom activities and preparation time with inside class room activities (Berrett, 2012. EDUCAUSE, 2012; Johnson et al. 2014). With the digital knowledge revolution there is a high potential of flipped classes where students can pick up the course content beforehand by themselves and profit from the time with their professor in class. The immediate in class feedback on in class exercises, computer based quizzes, case studies solving, or practical simulations (like simulating the design process of a complex construction detail) allows the professor to identify where the difficulty lies with students and foster deep learning and interaction.

In this context, the study aims to assess the students' learning experience and level engagement using qualitative and quantitative evaluation methods. The importance of this study is significantly highlighted in fostering deep learning and better understanding of the course subject matter, structure and domain of sustainable building technology. Secondary, the study provides a reflection on the learning methods, students' motivation, engagements and attitudes in this early learning process experience in engineering higher education. With its focus on the design experience and knowledge uptake this article will be of interest to engineers, architects, educators and researchers concerned with engineering education of sustainable development (EESD). The article determines the needs for pedagogical and educational engagement to ascertain and quantify the effort needed to understand and apply sustainability principles of building technology in future curricula. This paper is organized into six sections. The first section identifies the research topic. The second describes similar courses and courses that have been presented at previous EESD conferences aiming to describe the state of the art. The third section identifies the research methods and course evaluation metrics and setting. The analysis of the results and the self-reported survey and questionnaires findings are presented in Section 4. Section 5 discusses the research finding and study limitations along with implications for future teaching and education. The final section provides a summarizing conclusion.

## 2 State of the Art

### *2.1 Personal Observation*

Driven by the low independence and autonomy of postgraduate students at the Faculty of Applied Sciences at the University of Liege (ULg) the author opted to adapt the enriched skeleton map as an interactive and self-regulated learning teaching technique. The passive role of many students in class, their basic reading performance and full dependence on the professor triggered the idea of applying the inversed class concept. My observation about students in higher education in engineering schools is that many of them aren't triggered enough to achieve deeper, meaningful learning. They often demonstrate a basic approach to factual learning with limited knowledge processing. In practical project conditions many of them often reveal the deficiencies of insufficient meaningful learning. The problems get magnified when most professors opt to examine student's ability to memorize context free knowledge, presentation skills or linguistic skills. In fact, many professors learn little about student assessment and evaluation (Zlatkin-Troitschanskaia, et al 2015). On the other side, the labor market's main critique to fresh graduates is their inability to use their knowledge and their lack of methodological skills (Zlatkin-Troitschanskaia, et al 2016). Therefore, middle and large companies create their own assessment centers to measure candidates' abilities of complex problems and case study solving, contextualization and correlation creation and the ability to apply their field knowledge.

At ULg the main author had the opportunity to teach courses on Sustainable Building Construction Technology in Bachelor year one and two followed by an architectural studio in Bachelor year three. In the architectural studio, students are expected to apply the knowledge and skills developed in their first and second year courses. The studio is project oriented reflecting student understanding, knowledge retention and skills mastering regarding sustainable architecture and building construction technology (Attia 2015a and 2016ab). However, we observed in the last year's low knowledge retention and inability to apply the first year and second year courses content in the third year studio. Therefore, we conducted this study to stimulate deep learning and trace the root cause of this problem.

### *2.2 Past research*

There is a limited body of literature examining the effects of introducing blended and interactive centered teaching methods in the engineering curricula on the students' knowledge and skills and final learning outcomes (Pereira et al. 2007 and Tune et.al 2013). For this study, three screening criteria were used to review conference and journal articles to a focused set of representative studies: (a) representing domain knowledge by concept maps; (b) effectiveness of using blended learning; and (c) research that focus on architectural and engineering curricula.

For examples, the paper of Elen (2011) aimed to identify the reasons to move towards the flipped classroom. The engineering schools of Belgian Universities invested in the last 20 years in IT infrastructure and possess a solid infrastructure that allows faculty and students to pursue their teaching activities online and offline. The physical class room and course material hardcopies are not any more the only medium for learning activities. The ease of using and accessing electronic content by all students through Blackboard (eCampus at Ulg), online courses and MOOCs facilitate blended learning. Today, we have variant pedagogical choices as faculty and do not need only to stick to ex-cathedra. In literature, we find several publications recommending (High Level Group, 2014) us to diversify out teaching method and look for the most fit to purpose (in this case learning outcomes) choices. Examples of that include reinforcing the link between theory and practice, motivating students, promoting self-learning, providing quantity and quality feedback, stimulate interaction and support active learning (Marée 2013). In their research on the choices fit to purpose docimological approach, Gilles et al. 2011 demonstrated the influence of contextual variables and more precisely constraints (number of student time resources available, assistants available, etc.) on those choices. But in recent years, the level of constraints on university faculty has continued to grow. The pedagogical mutation represented by flipped classes intertwines with economic, sociological, technological, administrative, structural transformation (Barber et al. 2013, Rege Colet and Romainville, 2006).

## 3 Method

The author provided the course handouts at the beginning of the semester and required from students to develop weekly an Enriched Skeleton Map (ESM) (see section 3.2) before and during each class (Marée 2013). The study was performed within the Sustainable Building Construction Technology Course 1 by the freshmen of the Bachelor of Architectural Engineering program (N=27 in 2014 and 2015) and the third year civil engineering students (N=8 in 2014 and 2015).

### *3.1 Curriculum design*

The course “Sustainable Building Construction Technology” is aiming to address sustainable architecture and conceptual design from a technical, constructive and material science perspective (ARCH3258-A, 2015). During the study semester we explore the basic and concepts of building construction approaches and technologies in order to serve architectural projects. This course is designed to deeply study sustainable building techniques and principles. The course explores the construction elements, and constructive approaches in parallel to performance of the various building materials and their implementation in construction. The course is structured into three main parts: 1) Design and materials, 2) construction timeline on site and 3) thermal bridging details. The topics will be presented in logical order to achieve a deep understand and ideal representation of sustainable building construction technology. The following topics are studies during this course:

- Sustainable design and construction, and life cycle assessment of buildings.
- The anatomy of buildings (spatial, structural and material)
- Building construction systems (bearing walls and wood frames, foundations, walls, slabs, beams, roofing)
- Building materials (classification, usage and properties)
- Construction timeline
- Thermal bridging details

At the end of this course the student should be able to:

- Observe and represent building construction details.
- Learn the systems and methods for a supporting structure and envelope systems.
- Learn the main building materials and their technical implementation.
- Read, interpret and draw technical schemes.
- Apply, link and propose different technical concepts based on different structural systems.

### *3.2 Enriched Skeleton Mapping*

ESMs, in contrast to the skeleton concept map of Novak and Cañas (2008), are the visualization of the conceptual structure of a specific knowledge domain. Each concept in the ESM contains (1) annotated factual information that elaborates on the concept and (2) an attached worksheet to formulate the meaning of the concept (Marée et al. 2012). The skeleton concept maps are enriched with multimedia content and a worksheet to provide scaffolds to improve students' knowledge construction (Attia

2015b, (Marée 2013). Using multimedia rich content (text, video clips, technical drawings, 3D models (Lupion Torres, 2009), pictures and animations) students developed 12 mini concepts under the collaborative interaction and argumentative logic (Attia 2015b). Students were expected to organize their interaction and collaborative learning through the use of roles, activities, and sequencing of activities and translate that into ESMs.

### *3.3 Assessment of students' self-reported behaviours*

The students were divided into two classes. The first group was used as a control group of third year civil engineering students (N=8, 4 women, 4 men, aged 20-21 years). The control group received the regular ex-cathedra classes during the first four weeks of the semester with a weekly quiz and class discussion. The lectures were structured as a linear sequence of slides following the course themes and structure explained earlier. On the other side, first year students (N=27, 14 women, 13 men, aged 17-18 years) received flipped classes and developed ESMs and mini concepts. Each week students had to work during two sessions. In the first session, a general multi-layered skeleton map was drawn collaboratively on the class board. Through argumentative debating and consensus based discussion the multi-layered skeleton map was created based on the previously read lecture handouts. Then the second session followed by dividing the class in group of two where each group has to enrich the skeleton map with a multimedia rich content. Every week a student was responsible to draw and share the class developed ESM using MindManager program on ULg Blackboard (eCampus). The theoretical content was the same for both classes and the two teaching methods were applied and administered until the end of the semester.

The effect of the ESM on the quiz grades and students' interaction was measured. Both groups had the same multiple choice tests three times during the 12 study weeks including the final examination. The evaluation of the exam was based Bloom's taxonomy that requires understanding, application, analysis and evaluation (Bloom 1956).

## 4 Results

### *4.1 Assessment of students' knowledge, skills, and attitudes*

The differences between the groups of scores were measured. According to the overall means the quiz grades of the second group improved at least by 28 percent and the students reported their increased interest in the course. The course attendance was 100% during the last 6 weeks and some students arrived half an hour earlier to the class to rehearse the weekly map. The finally produced ESMs were evaluated regarding their content quality and were graded independently.

At the completion of the course, 22 (81%) of students agreed that the ESM improved their ability to meet the learning objectives either well or very well. Eighty-five percent, on average, agreed strongly that the curriculum and learning modalities were useful in to apply their knowledge in the ESM. Ninety-two percent, on average, agreed or strongly agreed that the curriculum would be of benefit to their future career, and on average 78% recommended that the curriculum be continued for future architectural school classes.

### *4.2 Curriculum Evaluation*

As students worked together as pairs we had the impression that the ESM helped them in scoring higher during the multiple choice questions exams. The positive feedback of students by the end of the course provided through an online questionnaire confirms the increased interest, knowledge uptake and independence. One of the interesting results was that students required less guidance and engaged in high quality discussions.

## 5 Discussion

All members of the engineering academic world, including architectural engineers, should be able to recognize the importance of applying the blended learning in their curricula. Students should be able to systematically apply self-regulated interactive learning methods for the core subjects with a thorough understanding of content. Our results demonstrate that an undergraduate flipped course based on ESMs and mini concepts development were well received and led to some changes in first-year architectural engineering students ‘knowledge, skills, and attitudes. We believe there are several sets of factors that contributed to these results. The first is the curriculum itself, including the course content, instructor effectiveness, educational modalities, timing and integration topics within the overall curriculum, planned redundancy, and evaluation methods. The second comes from other formal or informal learning experiences within the pre-architectural and architecture study years, including hidden curriculum.

### *5.1 Curriculum characteristics*

Our analysis identified aspects of the curriculum that worked well for our first-year architectural engineering students. We believe that presenting the flipped course content at Bloom’s (1956) taxonomy of higher order thinking skills (understand, apply, analyse, evaluate, create) and the interactive nature of the learning modalities contributed to the improved responses after students participated in the curriculum. For example, the most improvement was seen in items addressed by ESM development sessions, such as the mini concepts discussions and the bi-weekly follow up corrections, where students applied knowledge and practiced skills. Conversely, students’ improved mastering of content delivered solely by reading, such as concepts and principles of sustainable building construction technology reported in slides, or in their enriched maps. These results and the curriculum evaluation suggest that interactive self-regulated learning may achieve deeper learning and more lasting impact of students’ knowledge, skills, and attitudes, as well as improved student satisfaction with the curriculum. The effect of the ESM on the quiz grades and students’ interaction was significant. Some student showed resistance during the early weeks until the whole class got used to the ESM concept. The following items list the advantages of the ESM:

- This method increases the interactivity, all students are actively involved.
- Students work collaboratively. This work environment reduces the competition that can be seen between students. The objective of this collaboration is to develop and sharpen their knowledge and not to select the best student (van Boxtel et al., 2002).
- It combines various teaching techniques: the confrontation with peers, oral presentations, debate, discussion, research ...
- It increases the autonomy of the students, their productivity and creativity. Indeed, once the lecture notes published, they are already out of date because of new techniques or new publications have been possible. The ESM allows students to interact and produce additional equipment compared with lecture notes autonomously and creatively (Cañas et al., N.d.).
- This method allows overcoming the limitations of the course using data available beyond the lecture notes in order to obtain up-to-dated knowledge (Tergan et al., 2006).
- This method is promising to develop skills in relation to classical ex cathedra lectures and podcasts.
- Education has more to coaching, coaching the active and independent student learning rather than transmissive teaching.

### *5.2 Study design, questionnaire, and evaluation tools*

Limitations in our study design, questionnaire, and evaluation methods also may have blunted the effects of our curriculum on student's learning. A stronger study design would have included a control group of Ulg students or students from same study year and specialisation. However, the study remains limited due to the lack of evidence based evaluation of the effectiveness of this technique. The next step of the study will investigate the ability to apply objective and comparative evaluation to assess the effectiveness of this teaching technique. Suggested improvements included changes in the timing of the curriculum, shorter sessions, less lecture and more personal follow up sessions, more guidance on communication issues. Ultimately, our study is limited due to the small population size, and the self-reported outcomes, rather than using observational methods to determine their actual performance or measuring retention outcomes with respect to the course content.

## 6 Conclusion

The effect of the ESM on the quiz grades and students' interaction was significant. Some students showed resistance in early weeks until the whole class got used to the ESM concept. The quiz grades improved at least by 20 percent and the students reported their increased interest in the course. The course attendance was 100% during the last 6 weeks and some students arrived half an hour earlier to the class to rehearse the weekly map. In conclusion, the positive feedback of students by the end of the course provided through an online questionnaire confirms the increased interest, knowledge uptake and independence. One of the interesting results was that students required less guidance and engaged in high quality discussions. On the other side, following the flipped class method as an innovative teaching method in class faced resistance and required determination and continuous persistence from the authors. However, the study remains limited due to the lack of evidence based evaluation of the effectiveness of this technique. The next step of the study will investigate the ability to apply objective and comparative evaluation to assess the effectiveness of this teaching technique using a control group from the same class and involve other teachers in the study.

## 7 Acknowledgement

The author gratefully acknowledge Ton Maree from TU-Eindhoven and Jan Hensen for their dedication to explain and apply the ESM concept, Guirec Ruellan for his assistance in teaching, the IFRES (Institut pour la Formation et la Recherche en Enseignement Supérieur) Faculty of Applied Sciences, Argenco Department, and all students who participated in the curriculum.

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# Is there a role for interprofessional education (IPE) in the future of Engineering Education for Sustainable Engineering?

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**Abstract**

The similarities between sustainable development and long-term management of chronic illnesses were highlighted in an earlier paper (Siller et al. 2015). This paper presents a new framework for engineering education that draws from the concept of 'interprofessional education' (IPE) developed for the health care system. The purpose of IPE is to better prepare future professionals to work cooperatively in the increasingly complex world of health care. The complexity of the health care system is mirrored in the technology enterprise system (Siller, et al. 2015) that deals with the human-designed world we are trying to sustain. The standard definition for IPE is that it includes two or more professions that learn: from, about and with each other. This is not something that has generally been applied to engineering education. While there are pushes to learn about other professions, rarely do engineering students learn from other professions and even more unlikely is there a situation where engineers learn jointly with other professions. Therefore, in this paper we propose a framework for an interprofessional approach to engineering education based on the lessons learned from IPE in health care education.

## 1 Introduction and Background

Today's "wicked" social problems (and sustainable development is one of them) require more complex, dynamic solutions that are largely characterized as uncertain, complex, ambiguous, and interdependent (Nandan and London 2013). Leaders face requirements to simultaneously meet multiple (often competing) needs and solve/manage complex problems. Increasingly universities are expected to be engaged with and prepare students to work with other professionals from different disciplines on socially relevant issues. Nandan and London (2013) stated that social change initiatives are best undertaken from an interdisciplinary approach that is more holistic, complex, and dynamic. Various authors have identified competencies needed for effecting social change including collaboration, communication, critical thinking, contextual competence, leadership and adaptive competence, courage, willingness to listen to different perspectives, desire to negotiate, ability to be respectful and supportive of different opinions, group work and group process skills.

Professional work often operates at the intersections of disciplines among heterogeneous groups of people. Typically, interdisciplinary teams are found in the workplace not in academia. Therefore, graduates have not learned and developed the competencies required for or been socialized into interdisciplinary work. Interprofessional work includes a different set of values, codes of conduct, and ways of knowing. Traditional higher education pursues deep specialization and reductionist approaches within tightly bounded disciplinary silos that create "cognitive and social boundaries" hindering collaboration and innovation (Nandan and London, 2013).

To counteract these silos and shortcomings in professional preparation, medical education has turned to the concept of InterProfessional Education (IPE). One definition for IPE states: "… as an educational intervention during which members of more than one health and/or social care profession learn interactively together, for the purpose of improving collaborative practice and/or the health/well being of patients/clients." (Reeves et al. 2008) IPE is designed to explicitly breakdown the silos in education.

Interprofessional thinking is a 21st century requirement for the complex, diverse situations facing society—especially those not reducing themselves to disciplinary boundaries. Post-modern society requires the collaboration of experts from multiple disciplines for grappling with today's complex, dynamic problems. The challenge is to avoid merging one discipline into another and instead to integrate the expertise and perspectives from multiple disciplines.

IPE facilitates and is enhanced by systems thinking and generative, transformative, and adaptive learning—each of which is enriched by interactions with others having alternative viewpoints and assumptions. Adaptive learning is enriched by alternative views in pursuit of the right answer to a puzzle. Generative and transformative learning are enriched by challenging assumptions and understanding alternate views when there is no right answer (Nandan and London, 2013).

Challenges to IPE include faculty unfamiliarity with and biases against other disciplines, as well as student unfamiliarity and biases. An interdisciplinary mindset recognizes the limitations of one's own profession and appreciates the different views and expertise of other disciplines.

Hean, et al. (Hean et al. 2012) proposed three theories to help inform IPE: social capital—which helped healthcare professionals focus on the benefits/resources of participating in social networks, as well as the inequities of social structure; social/adult learning—that informs the learning and teaching process; and sociological theories—that explain the social construction of learning and work, as well as the interactions among groups of people. The application of these theories to engineering education requires recognizing the social capital associated with sustainable development. Also, the types of questions regarding social inequities are as critical an issue for sustainable development as they are for healthcare.

The similarities between sustainable development and long-term management of chronic illnesses were highlighted in an earlier paper (Siller and Johnson 2015). Continuing with that analogy a new framework for engineering education can be considered that draws from the concept of 'interprofessional education' (IPE) developed for the health care system. The purpose of IPE is to better prepare future professionals to work cooperatively in the increasingly complex world of health care. The complexity of the health care system is mirrored in the technology enterprise system (Siller, et al. 2015) that deals with the human-designed world we are trying to sustain. The standard definition for IPE is that it includes two or more professions that learn: from, about and with each other. This is not something that has generally been applied to engineering education. While there are pushes to learn about other professions, rarely do engineering students learn from other professions and even more unlikely is there a situation where engineers learn jointly with other professions. Therefore, in this paper we propose a framework for an interprofessional approach to engineering education based on the lessons learned from IPE in health care education.

## 2 Implementation Approaches

To define our framework, we discuss several implementation issues. First, when should IPE take place: before or after graduation? For engineering the best choice would be before graduation. The challenge always seems to come down to the concern that there is no room in the curriculum for additional components -we agree if one is unwilling to remove some existing content. Engineering is a profession that does not always require a graduate degree for entrance into the profession. In the United States (US), for example, the American Society of Civil Engineers has developed a Body of Knowledge, (Committee 2003), that extends beyond the undergraduate degree, but opposition from other professional societies has prevented implementation of a requirement for a graduate degree for licensure in engineering in the US. Therefore, there are few options in the US to introduce engineers to IPE approaches post - baccalaureate degree. This creates challenges as undergraduate curricula are already fairly crowded and these students are still in the process of developing their engineering skills and might, therefore, lack the maturity to fully appreciate an IPE approach. Despite these constraints, IPE still provides a framework that has the potential for implementation towards the later years of the undergraduate degree programs.

Next, how best to structure the IPE experience? Should it consist of team project work that includes multiple professions, or should it be course-based education? Teams-based approaches have been tried in engineering capstone design courses but such an approach has yet to result in a strong version of IPE. The reality is that when engineering capstone courses do involve teams that incorporate other professions they often treat the other professions as support mechanisms for the main goal of a technological solution. This can be changed by redefining problems away from being primarily technical -more on this below in the example implementation section.

There are a couple of other important issues to be addressed, 1) which professions would be included?, and 2) and who will deliver the content? The participating professions in health care may now seem obvious, but for engineering what professions are most important to the technical enterprise is a topic explored in this paper. The second question touches on a recommendation about IPE that might be very problematic for engineering educators: the need to break down the sense of hierarchy within the professions. In a technological enterprise it seems natural that the technologists (engineers) hold a privileged place in the system. We have seen this mentality emerge in engineering students (and faculty) for years, so we face a tough challenge if we are to adopt IPE for engineering education, as it will require other professions engaging in the teaching role. Historically engineering has depended on others, e.g. mathematicians and scientists to teach content to engineering students, but this rarely has been the case that these others are considered equally important in a collaborative environment.

The first step towards adopting the IPE approach is to redefine the problems being worked on as social-technical problems and not exclusively technological problems. As discussed above, it is important to not have a sense of hierarchy between the participating professions for IPE to be successful. If a problem is initially associated with technology, this is an implicit statement of hierarchy. In the following example we first use a new classification system for infrastructure that identifies the interdisciplinary aspects of these projects. From this we can identify several professions that can be productively brought together to engage in IPE. This then leads to an approach for involving engineering students in IPE-based educational activities.

### *2.1 Sustainable Infrastructure*

Infrastructure projects represent some of the largest human-made structures that impact the natural world. Often they can be quite destructive to both the physical environment and cause harm to social systems, for example the U.S. interstate highway system has led to major social changes in where people live, work, and the amount of travel that occurs in individual vehicles instead of mass transit systems. (Lewis 1997) The Institute for Sustainable Infrastructure (ISI 2016) recently developed a rating system for infrastructure projects, Envision™. In this rating system there are five major categories of metrics used to create a sustainability score: (1) Quality of Life, (2) Leadership, (3) Resource Allocation, (4) Natural World, and (5) Climate and Risk. This list highlights the breadth of the interdisciplinary nature of infrastructure projects. Herein, we use this system as a basis to develop an IPE approach that could be implemented for engineering undergraduate programs in collaboration with educators in other professions.

### *2.2 Envision™*

Table 1 shows a portion of the credit list used in the Envision™ system; this portion being the quality of life indicators. By taking a glance through the list of topics it becomes apparent that the sustainability of infrastructure projects involves many disciplines. For example, the rating requires estimates on topics such as the preservation of historical and cultural resources. These are areas that do not typically fall within the domain of engineering expertise. This list can help us to answer one of the first questions necessary for implementing an IPE project: who should be involved? For example, QL3.1 refers to the historical and cultural resources being preserved –this will require contributions from experts in these areas. Lewis (1997) provides an excellent example regarding the push to place an elevated highway along the river in New Orleans, US, in the 1960's during the height of the interstate highway efforts. In his book he chronicles the historical development of the street system in New Orleans back to the 1700's. The proposed interstate highway did not acknowledge this existing street network, was eventually opposed by a group of preservationists (in the name of protecting an historical resource of the French Quarter District of New Orleans). The highway would have effectively destroyed much of the existing riverfront district. The opposition eventually took their fight to the national level and won, thereby preserving a valuable historical regional that remains an important resource in New Orleans today. During this battle, the engineers originally failed to acknowledge the social nature of the issue as the technical aspects were easily resolved but they missed both the historical importance of the region and did not understand the political capabilities of the local population. It serves an excellent example where interdisciplinary approaches at the beginning may have avoided years of political battles. These types of projects continue today and would serve as excellent educational case studies to engage students from numerous professions in a joint planning process using an IPE-based approach.

Historians and political scientists are just two examples of other professions that can be seen as valuable from the short section of Envision™ illustrated in Table 1. Other professions come to mind upon further review of Table 1 and the full version of the system available online. For example, the issues of minimizing noise and light pollution immediately highlight the contributions architects and urban planners would have in encouraging alternative modes of transportation (QL2.5, Table 1). Ultimately, the breadth of professions to include will always be dependent in some part on the nature of the projects being considered.

*Table 1: Envision$^{TM}$ Quality of Life Credit List*

| | | Y | N | NA |
|---|---|---|---|---|
| PURPOSE | QL1.1 Improve Community Quality of Life | 0 | 0 | 3 |
| | QL1.2 Stimulate Sustainable Growth and Development | 0 | 0 | 3 |
| | QL1.3 Develop Local Skills and Capabilities | 0 | 0 | 3 |
| COMMUNITY | QL2.1 Enhance Public Health and Safety | 0 | 0 | 1 |
| | QL2.2 Minimize Noise and Vibration | 0 | 0 | 1 |
| | QL2.3 Minimize Light Pollution | 0 | 0 | 1 |
| | QL2.4 Improve Community Mobility and Access | 0 | 0 | 3 |
| | QL2.5 Encourage Alternative Modes of Transportation | 0 | 0 | 2 |
| | QL2.6 Improve Site Accessibility, Safety and Wayfinding | 0 | 0 | 3 |
| WELLBEING | QL3.1 Preserve Historic and Cultural Resources | 0 | 0 | 2 |
| | QL3.2 Preserve Views and Local Character | 0 | 0 | 2 |
| | QL3.3 Enhance Public Space | 0 | 0 | 2 |
| | TOTAL | 0 | 0 | 26 |

## 2.3 *Pedagogy*

The next step in developing our IPE experience is to decide on the structure or pedagogical approach. As mentioned above there are several approaches that can be implemented, e.g. Jointly taught classes, project-based approaches, etc. For engineering educators, the natural tendency is to incorporate some type of project as the focus of the experience. But we must be cautious as this same mentality might not be the norm in other disciplines. Let' return to the example highlighted in Table 1 and consider working closely with historians to develop a project that preserves historical and cultural resources.

In the quote below, a capstone experience course for history majors at Colorado State University provides a description of the course objectives (CSU History Dept 2016):

> *students will practice the usual history capstone skills—primary-source research, historiography, writing, peer-review, and citation*

Notice this is focused on skill development and use, similar to engineering education. Now let's contrast this with the criteria for U.S. engineering programs accredited by ABET, Inc. Senior engineering capstone experiences must meet the following objective (ABET 2016):

> *Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.*

This learning objective, similar to that found in the history course, requires the students to use the skills of the profession. But note: the statement starts with requiring a design experience that is expected to result in a tangible design *product*. Clearly these two capstone experiences have course objectives that are different enough to lead to different pedagogies. Engineering students spend a semester or two working on team design projects while history student spend more time on analytical work honing their skills. Yet these are the types of students we need to bring together in an IPE experience. The basis for bring these students together resides in both groups needing to use their skills in their respective areas on a capstone experience. An example case similar to the one mentioned above, the highway in New Orleans, could serve as a point of connection where both engineers and historians could learn to jointly practice their professional skills. This would afford the students the opportunity to learn about and from each other while learning with each other –the main elements of IPE.

### *2.4 IPE approach*

Let's develop an example to implement an IPE approach for historians and engineers to learn together with a focus on an infrastructure project. The first step in this process we have designated as the Diagnostic Stage to draw a parallel to the implementation to how IPE is used in medical education. At this stage both professions, historians and engineers, would be brought together to *diagnose* the issues related to an infrastructure problem. This can be done in a couple of ways. Students could enroll in a common course or separate courses that are tied together through a series of combined assignments. Either approach may work as long as there is mutual accountability for the students' efforts. Both models have been used at Colorado state University where an engineering senior design course was connected to a College of Business course for one semester of joint efforts, and another engineering senior design course included students from two different majors to work on an in disciplinary project. In the first case, joint courses, each department maintained their own set of procedures while the students worked together on the project. The collaboration was not as tight as in the second example but was easier from the standpoint of the departments being responsible for their own students. In the second case, where students enrolled in a single course, the integration of the students efforts was deeper, partly due to them all being engineers, but issues of responsibilities for grading did become an issue for the students and faculty.

The key objective is to bring both professions together, including faculty and students, to engage in the problem definition stage and to share their different professional perspectives. This is the critical step where the shift in rhetoric from defining issues as being *technical* problems to *social* problems must occur. What must be avoided is to allow the engineers to define the problem and engage historians as consultants to the project. Once this joint definition is established it needs to be reinforced throughout the remainder of the joint experience.

Here is when the Envision system provides the incentive for the IPE effort –the sustainability of a project must clearly address the areas of expertise of multiple groups. Additionally, to truly engage in interdisciplinary work each group must work together such that their expertise informs each other's efforts, instead of being multidisciplinary where they just work side-by-side.(Frodeman 2010) Bringing the two groups together early in the process is similar to the methods used in medical education IPE where a case is diagnosed by a group of related professions. This step is the beginning of satisfying the IPE requirement that students learn with, from, and about each other's professions. The problem definition can be accomplished through a series of workshops where each profession contributes to a mutually developed understanding of the issues at hand.

After the diagnostic phase is complete, there would be time for each profession to proceed along their own lines of inquiry: engineers entering into the traditional design process while the historians engage in developing an historical perspective. The difference here will be that both efforts are informed by the mutually defined understanding coming from the first joint phase of their work. A key warning here is to not allow the joint effort to end at this point. During the remainder of the students' efforts, continued contact and mutual efforts must be maintained. This can be done through scheduled period working meetings where everyone comes together to share progress reports and to continue to learn from, with, and about each other.

At the completion of the IPE experience a final report that focuses on the entire effort of all members would be required. Notice this is not a traditional design project document as it would require a more comprehensive coverage of the contributions of all the collaborating professions. This report would need to evaluated by faculty from all the professions involved. The Envision checklist can serve as a rubric to judge the success of this mutually developed final product of the joint IPE efforts. The advantage of producing a joint report is the acknowledgment of the interdisciplinary aspect of the effort. There is a danger that if the groups produce separate culminating reports, these would be judged within the narrow views of the individual professions.

## 3 Discussion and Recommendations

In this paper we have presented the argument that the complexity of sustainable development requires rethinking how we educate engineers. An approach that is gaining acceptance in medical education is known as Interprofessional Education. IPE, we believe holds great promise for educating engineers. The power of this interdisciplinary approach is in bringing professionals together in an educational setting where all are on equal status, and where each participating profession is learning from, with, and about each other. To illustrate how this can be used in engineering, we introduced the recently developed Envision$^{TM}$ tool that is used for rating sustainable infrastructure projects. This system's checklist provides insight into what other professions can and should be engaged in an IPE experience with engineers and also provides a framework that can both drive the curriculum and provide a rubric for assessment. We then suggest one example approach for creating an IPE experience in collaboration with history educators.

To effectively implement our suggested implementation several concerns must be addressed. First, sustainable development must be defined as a social-technical issue, not only a technical issue. For IPE to work, there must not be a sense of hierarchy between the professions that can occur if we think of issues as always being technical in nature. Second we need to identify what other professions should be engaged in our efforts. In the example cited herein the case was made for historians, political scientists, and urban planners –the case for others can also be made. The Envision$^{TM}$ system provides metrics that are clearly associated with other professions, e.g. historians, sociologists, etc. Finally, engineering educators must find ways to allow for greater flexibility in the curriculum to allow for IPE-based experiences. The importance of the contributions of other professions to sustainable development goes beyond the traditional technical content so the curriculum must allow for their inclusion. The value of implementing IPE-based education in engineering education includes developing students' skills for working collaboratively with other professions to manage today's complex problems.

## 4 Acknowledgements

The authors would like to thank the anonymous reviews for their constructive comments to the original draft of this paper. This final version contains greater detail about how IPE could be implemented to educate engineering students on the topic of sustainable development.

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# Evaluation of a MOOC on “Sustainability in Everyday Life” - The teachers’ experiences

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## Abstract

Universities all over the world have been developing Massive Online Open Courses, MOOCs. In this paper, we discuss our experiences during the production of and running the MOOC “Sustainability in everyday life”, that was developed at Chalmers University of Technology. The MOOC ran over a period of 7 weeks, from early June until late July, 2015 and attracted about 9000 participants. The purpose of this paper is (1) to describe and evaluate the further development and content production, and subsequent running of the course; and (2) to share our experiences of running a MOOC for the first time. An action research approach, that focuses on the experience of the teachers, was combined with information obtained from the course statistics, and from the course evaluations by the participants. This approach was used to identify the challenges that were met during the development of the course material and running the MOOC. The results show that, on the one hand, the major challenges were the planning of the content production process and the formulation of the assignments. On the other hand, although time consuming, the production of the video content was perceived as a nice activity. The course statistics and evaluations by the MOOC participants reflected the teachers’ experiences to some extent, and this information can be used to improve the MOOC. The role of MOOCs in higher education for sustainable development (HESD) is not yet clear. This paper demonstrates that developing a MOOC from scratch is a complex process, and adaptation of on-campus courses may be a feasible alternative, thus making already existing courses more widely available.

## 1 Introduction

Massive Open Online Courses (MOOCs) have been growing in popularity as an online learning environment over the past couple of years. MOOC participants can be of all ages, all educational backgrounds, and they have an interest to learn more about a topic outside of a formal university curriculum. The number of participants can be massive, in excess of 250 000 participants (EdX, 2016b), creating opportunities but also challenges for the teachers and other actors involved. Universities all over the world are trying to reap the benefits by, for instance, using MOOCs as a tool (1) to brand the institution; (2) to open up higher education to a global audience; and (3) to build up experience in developing, implementing and evaluating MOOCs (Janssen & Stöhr,2015).

Chalmers University of Technology has recently also become active in the MOOC arena. So far, Chalmers has published four MOOCs on the EdX platform (EdX, 2016a) of which one is the MOOC that is in focus in this paper, called "Sustainability in Everyday Life" (SiEL). The SiEL MOOC was first run over a period of 7 weeks, from early June until late July of 2015, and close to 9000 people enrolled in the course before its start. The SiEL MOOC targeted the informed citizen, which in the EU is defined by the 15-year old student passing the final national tests in compulsory school. The learning outcomes aimed at developing the participants' capacity to

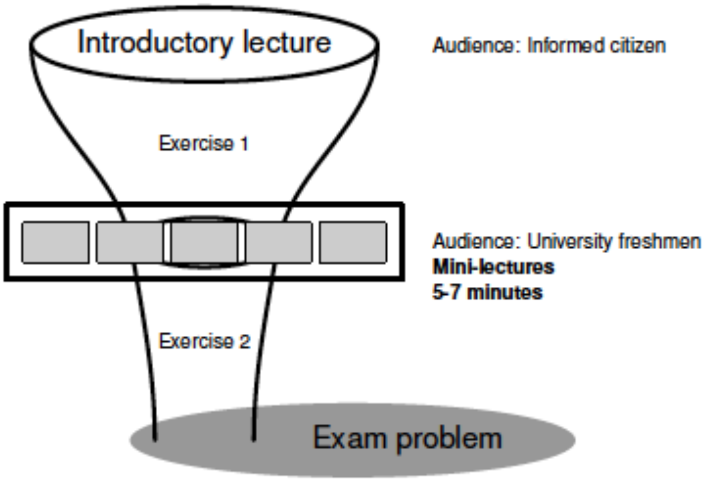


Figure 1: Addressing the topics in the SiEL MOOC: from an introduction to the topic, via more mini-lectures that discuss aspects in more detail, to the course exam (taken from Janssen, Nyström Claesson, and Lindqvist (2016))

appreciate the complexity of sustainability in everyday life by developing skills such as systems thinking and critical reflection on the information flow in the media. Five topics were identified that are frequently addressed in the media and are at the forefront of research related to sustainable development. These topics were chemicals, climate, energy, food and globalization, and they were used as the main themes around which the course was developed. All of these topics were taught as depicted in Figure 1. This started with a 15-minute lecture that provides an introduction to the topic. This was then followed by several so-called mini-lectures of 5 to 7 minutes which address several aspects that are part of the topic in more detail. Finally, the participants were asked to incorporate all of the five topics in answering the problem given in the course exam.

While we described our (the teachers') experiences during the design and early development of the SiEL MOOC in Janssen, Nyström Claesson, and Lindqvist (2016), the purpose of this paper is (1) to describe and evaluate the further development and content production, and subsequent running of the course; and (2) to share our experiences of running a MOOC for the first time. The paper continues with a literature review on the experiences of teachers in MOOCs and the role of MOOCs in higher education for sustainable development (HESD). This is followed by describing the applied evaluation methodology, the results and their discussion, and conclusions are made.

## 2 Literature review

The recent surge in the number of MOOCs launched on platforms like EdX, Coursera or Futurelearn has received a lot of attention. This attention has resulted in increased scrutiny of MOOCs regarding e.g. their academic creditability (Kolowich, 2013), educational value (Kellogg, 2013) and instructional design quality (Margaryan, Bianco, & Littlejohn, 2015). One of the topics that has not received a lot of attention is the role of the teachers and their motivations for engaging with MOOCs. Ross, Sinclair, Knox, Bayne, and Macleod (2014) showed that the presence and visibility of MOOC teachers is an important issue, and that paying attention to the complexity of the teacher's experience and identity may determine the success of MOOCs as an educational format. Stöhr, Eriksson, and Adawi (2015) found that, among others, experimentation with something new and innovative, and teaching a MOOC as contributing to their professional development were motivations of the MOOC teachers involved at Chalmers University of Technology.

Implications of MOOCs on higher education were discussed by Yuan and Powell (2013). They argue for establishing an autonomous business unit in order to make an appropriate response to the emergence of online teaching innovations such as MOOCs. Jacoby (2014) reviewed the disruptive potential of MOOCs and she concludes that the impact of MOOCs on higher education will besignificant via changes in definitions of completion, pedagogical approaches, delivery methods, certification, and business models. Studies in an American context also focus on the cost of higher education and tuition fees. The cost factor may play a big role in changes in on-campus education, and may help to alleviate related problems such as unsustainable costs and unmanageable student debt (Dennis, 2012; Billington & Fronmueller, 2013).

There is a significant body of work on higher education for sustainable development (HESD) that focuses on, among others, the development of competencies for sustainable development (Barth, Godemann, Rieckmann, & Stoltenberg, 2007) and their integration in higher education (Lambrechts, Mula,` Ceulemans, Molderez, & Gaeremynck, 2013), and learning outcomes of education for sustainable development (Svanström, Lozano-Garc´ıa, & Rowe, 2008). However, to the knowledge of the authors, there has been little work done on the role of MOOCs in HESD, or on their contribution to HESD. Zhan et al. (2015) provide a content analysis of sustainability education in MOOCs based on 51 courses. These MOOCs provided mainly introductory-level courses without prerequisites. Some of the main topics identified were energy, natural resources, ethics and climate change. Videos and discussion forums were mostly used for the teaching, and forums regarding lecture reflection were popular. Nevertheless, it remains unclear how and to what extent MOOCs may contribute to HESD.

## 3 Research method

A mixed method approach (Johnson & Onwuegbuzie, 2004) was taken to describe our (the teachers') experiences and to evaluate the content production for and running of the SiEL MOOC. An action research approach, that focuses on the experience of the teachers, was combined with an analysis of the information obtained from the course statistics (quantitative), and from the course evaluations by the participants (quantitative and qualitative).

Action research is grounded in experience, and is action-oriented and participative (Reason & Bradbury, 2001). Furthermore, Baskerville and Myers (2004) argue that action researchers need to be participant observers, and that a collaborative team is involved in reasoning, action formulation, and action taking. In our previous paper about this MOOC (Janssen et al., 2016), we also took an action research approach in order to share our first experiences regarding the MOOC's design and early development, and to identify our role(s) and its features during the course design and early development. We chose to use the action research approach again because, besides being the designers of its concept, we were all involved in the further development of, content production for, and running, the SiEL MOOC.

The goal of using the mixed method approach is to strengthen the results obtained from the action research with both additional quantitative information, such as learning analytics data, and qualitative information, such as the course evaluations by the participants. This may provide a deeper understanding of our experiences and how these correspond to the experiences of the MOOC participants. This does not mean that one methodology can explain the results of the other. When the results from different approaches converge they confirm each other, and when they diverge they highlight areas that need alternative and richer explanations.

## 4 Results & discussion

### *4.1 Video production*

Four types of videos that were part of the teaching material were recorded: (1) the introductory lectures and (2) mini-lectures for each of the five main topics (see Figure 1); (3) additional videos that contained introductory material to the MOOC in general, and further background material to the five topics; (4) update videos in which we addressed topics that were discussed on the course forum or in the popular media related to sustainability. In total, 51 videos with a total length of close to 6.5 hours were recorded.

Table 1: Number, length and complete views of the videos per topics in the MOOC

| Topic and kind of video | Number of videos | Average video length | Total video length | Average video completion |
|---|---|---|---|---|
| Introduction | | | | |
| Welcome | 1 | | 3 min 2 s | 81.0 % |
| Introductory mini-lectures | 6 | 5 min 34 s | 33 min 24 s | 71.8 % |
| Energy | | | | |
| Introductory lecture | 1 | | 14 min 39 s | 54.6 % |
| Mini-lectures | 4 | 8 min 21 s | 33 min 24 s | 73.6 % |
| Background videos | 1 | | 5 min 39 s | 79.8 % |
| Globalization | | | | |
| Introductory lecture | 1 | | 15 min 49 s | 63.5 % |
| Mini-lectures | 6 | 8 min 20 s | 49 min 57 s | 76.0 % |
| Background videos | 2 | 8 min 19 s | 16 min 38 s | 74.1 % |
| Climate | | | | |
| Introductory lecture | 1 | | 13 min 10 s | 68.3 % |
| Mini-lectures | 6 | 5 min 57 s | 35 min 41 s | 69.8 % |
| Background videos | 1 | | 6 min 6 s | 80.8 % |
| Chemicals | | | | |

| | | | | |
|---|---|---|---|---|
| Introductory lecture | 1 | | 16 min 16 s | 63.4 % |
| Mini-lectures | 5 | 7 min 48 s | 39 min 2 s | 73.8 % |
| Background videos | 3 | 7 min 1 s | 21 min 3 s | 72.2 % |
| Food | | | | |
| Introductory lecture | 1 | | 15 min 6 s | 62.8 % |
| Mini-lectures | 4 | 6 min 29 s | 25 min 57 s | 67.9 % |
| Background videos | 1 | | 8 min 58 s | 80.9 % |

### *4.1.1 First experience: The teaser video*

Our (the teachers, and the first two authors of this paper) first major experience with the production of video content was the production of the so-called teaser video. This is a promotional video whose goals are to introduce the MOOC before its start and to attract participants. Based on our own ideas and on the ideas of the production team, we wrote a script for a video of approx. 2.5 minutes. This was a very creative process which took several hours. We settled on a casual conversation among us with a competition element in it (Who of us has the most sustainability life style?) in order to introduce the different topics we would address in the MOOC. We were well prepared and the recording of the video went well. The teaser video was first shown at the launch of the MOOC, and was well received which gave us confidence for the recording of the other video material and a sense of pride.

### *4.1.2 Introductory lectures*

We were able to engage colleagues at our department, and who are leaders in their fields of academic expertise, for the recording of all of the introductory lectures. Two of these lectures were recorded with an audience on campus, an attempt to mimic the appearance of lectures such as those appearing on Ted. Two of them were recorded entirely on location, and one was recorded on location and in a studio. The average length of these lectures was 15 minutes (see Table 1). We discussed with them what we were going to address in more detail the mini-lectures related to their topic, but we did not give further instructions on how they should shape to their own lecture. The introductory lectures were well received by the MOOC participants. However, the completion rate for these lectures was lower than expected (from 55 % to 68 %, see Table 1). The length of these videos is most likely the main reason for this lower completion rate.

Table 2: Views and completion rates for update videos for all topics compared to total average number of views per video and completion rates during the same week

| Topic | Update topic | Number of update views | Update completion rate | Total average number of views | Total average video completion |
|---|---|---|---|---|---|
| Energy | | | | 796 | 71.1 % |
| Globalization | Energy | 606 | 77.7 % | 390 | 73.9 % |
| Climate | Globalization | 148 | 68.9 % | 286 | 70.7 % |
| Chemicals | Climate | 64 | 76.6 % | 244 | 71.7 % |

| | | | | | |
|---|---|---|---|---|---|
| Food | Chemicals | 38 | 81.6 % | 226 | 69.2 % |
| | Food | 31 | 66.7 % | | |
| | Final update | 22 | 71.0 % | | |

### *4.1.3 Mini-lectures and background videos*

Most of the recording of the mini lectures was done in a sprint over a 3-week period. We tried to engage more of our colleagues in this production process, but we were not entirely successful with this. We gave them the opportunity to suggest a topic, and tried to give them a sense of ownership. This did not work well because we had probably not been communicating well enough what we were doing in the MOOC. We (the first two authors of this paper) recorded almost half of all the mini-lectures ourselves and all of the background videos, and divided the workload according to the topics of the videos. This increased our workload in the MOOC quite significantly. The first step in the production of the mini-lectures was writing the scripts for them, and finding material for producing slides to be shown in the mini-lectures. Depending on the topic, this could be a fast or slow process. For instance, preparing the script for a 6-minute mini-lecture on a lesser known topic took a full day, while preparing a 11-minute mini-lecture on a well-known topic took half a day. Preparing the scripts for the mini-lectures was a learning experience, both in doing it and topic-wise.

During the recording of the videos we used a teleprompter that displayed the script. This made the recording of the videos highly efficient because very few retakes had to be done. One drawback the use of a teleprompter may be that it becomes apparent that the lecturer is reading from it, or that the lecturer is not animated enough and the listener loses interest. This was commented on by MOOC participants in the post-survey.

The average length of the mini-lectures and background videos varied per topic, from 5.5 min to 8.5 min. There also was a large spread in the length of these videos, from 4 min to 14 min (see Table 1). Furthermore, the average rate of completion ranged from 70 % to 81 %, and was thus higher than for the introductory lectures, except for the case of the climate topic. This may again be explained by the length of the videos.

### *4.1.4 Update videos*

We continued to produce content after the MOOC had started. We recorded weekly update videos in which we addressed issues that were discussed in the forum. We monitored the forum for such issues, and we tried to get involved in some of the discussions. One example of such a discussion was the problems that the MOOC participants had with some of the assignments that we constructed (see section 4.2). In the weekly updates we also addressed topics that were in the popular media that week and that were related to sustainability or sustainable development. One example of such a topic was the court ruling in the Netherlands in which the government was ordered to increase its efforts to cut carbon emissions from 14 % to 25 % (Neslen, 2015).

One of the goals of the weekly update videos thus was to further discuss the course material. However, the MOOC participants did not take advantage of this to a great extent (see Table 2). Except for the update on the energy topic, the number of update views was much lower than the average number of views per video during that week, and continued to drop during the MOOC. The

Table 3: Number of submissions and correct solutions for all topics and assignment types. Introductory assignment is related to the introductory lecture, weekly assignment is related to the mini-lectures.

| Topic and assignment | Number of submissions | % of correct solutions |
|---|---|---|
| Energy | | |
| Introductory assignment v.1 | 755 | 63.4 |
| Introductory assignment v.2 | 425 | 84.0 |
| Weekly assignment v.1 | 538 | 29.9 |
| Weekly assignment v.2 | 357 | 81.0 |
| Globalisation | | |
| Introductory assignment | 466 | 74.9 |
| Weekly assignment | 416 | 77.4 |
| Climate | | |
| Introductory assignment | 396 | 84.6 |
| Weekly assignment | 186 | 53.1 |
| Chemicals | | |
| Introductory assignment | 352 | 93.5 |
| Weekly assignment | 353 | 94.3 |
| Food | | |
| Introductory assignment | 327 | 83.5 |
| Weekly assignment | 312 | 83.7 |

completion rate was however similar to the completion rate of the other videos. This trend may question the pedagogical value of the update videos that we recorded.

### *4.2 Quizzes, assignments and exam*

For all topics we constructed assignments linked to the introductory lecture, and assignments based on the material discussed in the mini-lectures. Furthermore, we made a set of quizzes for each of the mini-lectures. All of the assignments and quizzes were graded. The quality of the first quizzes and assignments that we constructed unfortunately suffered from the amount of time we had available to invest in them. This was to some extent caused by the extra amount of time we had to invest in preparing and recording the mini-lectures and background videos (see section 4.1.3). We received a lot of criticism from MOOC participants on the forum about these assignments. Especially the introductory and weekly assignment for the energy topic were heavily criticized. The former required doing some calculations which was not appreciated, while the latter was a qualitative assessment of several future energy scenarios in multiple-choice form. Unfortunately, the first versions of these assignments were not well formulated. We decided to redo these assignments which improved their quality. The number of correct solutions increased significantly for both, from 63 % to 84 % for the introductory energy assignment and from 30 % to 81 % for the weekly energy assignment (see Table 3). For the weekly climate assignment we experienced technical difficulties with one of the questions (a drag-and-drop exercise) which resulted in a low percentage of correct solutions (53 %, see Table 4.2). After these problems during the first week of the MOOC, we engaged -testers in order to improve the quality of the assignments. This resulted in the desired effect because the number of complaints on the forum decreased significantly and the percentage of correct solutions was high (see Table 3). Besides the help of the -testers, we also quickly learned how to better formulate these assignments.

The last major production task was the construction of the exam. We had thought of creating a game before, but we abandoned this idea. Nevertheless, this idea was the inspiration for the exam we constructed. We asked the MOOC participants to construct two scenarios, one about a week in their everyday life, and one about a trip they would like to make. These scenarios needed to be constructed based on describing 5 activities, and finally they had to do an assessment of the sustainability of these scenarios. The results of this exercise were peer-assessed which was met with mixed feelings. While there were some questions and complaints about it, the exam was quite well received despite a problem with the grading of the exam. Some MOOC participants were of the opinion that it was too much work, but others enjoyed working on the exam.

### *4.3 Post-survey of the course and reflection*

The MOOC participants were asked to fill out a post-survey after the course had finished. In general, the results of this survey showed that the MOOC participants were positive about the course material. They particularly liked the choice of the topics and the videos that were produced. They were more critical of the ambiguous nature of some of the assignments (see section 4.2) and answers in the mini-lecture quizzes. This is also reflected in our own perception of the production of the course content. While time consuming, the production of the videos was a nice activity. The formulation of the quizzes and the assignments were more troublesome, but we were able to improve it by learning and by engaging -testers. The use of peer assessment was met with mixed feelings, especially in the exam. The good qualitative feedback can be taken to improve certain course elements before a re-run.

Our general perception was that almost everything that we did in the development of this MOOC was something new for us, and that we were on a steep learning curve. Examples were the writing of the scripts for and the recording of the videos, and the formulation of the asignments. The support of the production team was crucial to cope with all this novelty. Finally, although the production process did not always proceed very smoothly, the experience to be part of the team of this MOOC was very rewarding and a great learning experience. One of the main lessons we learned as teachers in this MOOC was that planning is crucial in the production phase and that there needs to be room to be agile.

## 5 Conclusions

This paper describes and evaluates the development and content production, and running of the MOOC "Sustainability in Everyday Life" (SiEL) at Chalmers University of Technology. It is a follow-up on the paper by Janssen et al. (2016) on the design and early development of this MOOC, and examines the teachers' perspective. The results show that, on the one hand, the major challenges were the planning of the content production process and the formulation of the assignments. On the other hand, although time consuming, the production of the video content was perceived as a nice activity. The course statistics and evaluations by the MOOC participants reflected the teachers' experiences to some extent, and this information can be used to improve the MOOC.

The role of MOOCs in higher education for sustainable development (HESD) is not yet clear. Designing and developing a MOOC from scratch is however a highly complex and time consuming process, especially when many people are involved. This is demonstrated in this paper for the SiEL MOOC. The time and effort needed should be considered beforehand. Building on material from an on-campus course, or adapting an on-campus course to a MOOC format may be an alternative to reduce the complexity of the MOOC development process. Courses with a focus on sustainable development offered at institutions for higher education may thus become more available to the general public. Offering such courses in a MOOC format may also reduce educational costs and make higher education more affordable and thus reach more people.

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# "DDI 101 L'ingénieur, source de solutions durables"[1] - Developing a MOOC[2] at Polytechnique Montreal

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## Abstract

Starting in 2007, the authors have been searching for ways to increase the integration of sustainability concepts in the engineering curriculum at Polytechnique Montreal (PM). A first attempt was to provide professors with ready-to-use examples of the application of sustainability principles in their areas of expertise, but uptake was minimal and the integration goal was not achieved.

In 2015, PM offered the Sustainable Development Office (SDO) the opportunity to lead the development of one of its first Massive Open Online Courses (MOOC). SDO accepted as it saw this project as an opportunity to bring together professors of PM from various disciplinary backgrounds and to develop pedagogical materials which could be reinvested in various courses. The development of the MOOC took approximately 18 months from the initial concept to the first diffusion.

The MOOC is structured as a six-week course, with first, an introduction to sustainable engineering, followed by five weeks touching on major issues: energy, mobility, resources, production and resilience. Several PM professors were invited to contribute. The response was overwhelming: 20 experts participate in the course. The resulting product meets the goal of the design team and, starting in fall 2016, the material of the MOOC will be available on a Moodle site open to all students and teachers of PM, allowing the various modules to be reinvested in existing courses.

In retrospect, it must be said that the authors plunged into this adventure with little understanding of the demanding aspect of this new media. Keeping coherence in structure and presentation proved to be a challenge. Unavoidable compromises were made to meet the deadline and several improvements are planned for the next version.

## Résumé

Depuis 2007, les auteurs ont cherché des moyens d'accroitre l'intégration des concepts de développement durable dans les programmes de génie à Polytechnique Montréal (PM). Fournir des exemples concrets de l'application des principes de développement durable dans leurs différents domaines d'expertise aux professeurs a donc été la première tentative officielle de diffusion transversale du développement durable au sein de PM. Néanmoins, leur utilisation a été minimale et les objectifs d'intégration n'ont pas été atteints.

[1] *Engineers: source of sustainable solutions* (our translation)
[2] Massive Open Online Course

En 2015, PM a offert au Bureau du développement durable la possibilité de développer l'un de ses premiers Massive Open Online Course (MOOC), cours ouvert gratuit et en ligne. Le Bureau a accepté voyant dans ce projet une occasion de réunir des professeurs de PM de divers horizons disciplinaires tout en élaborant du matériel pédagogique qui pourrait être réinvesti dans divers cours à PM. Le développement du MOOC a duré environ 18 mois, de la conception initiale à la première diffusion.

Le MOOC est structuré en un cours de six semaines, avec, en premier lieu, une introduction à l'ingénierie durable, suivie de cinq semaines sur les grandes questions touchant les domaines de : l'énergie, la mobilité, des ressources, la production et la résilience. Plusieurs professeurs de PM ont été invités à contribuer. La demande a été reçue avec enthousiasme et intérêt : 20 experts participent au cours. Le produit fini répond à l'objectif de l'équipe de développement et, à partir de l'automne 2016, le matériel du MOOC sera également disponible sur un site Moodle ouvert à tous les élèves et enseignants de PM.

Rétrospectivement, il faut admettre que les auteurs qui se sont lancés dans cette aventure avaient alors peu de compréhension et de connaissances quant aux exigences du travail avec ce nouveau média de formation. Garder une cohérence dans la structure et la présentation s'est avéré être un défi. Des compromis inévitables ont été faits pour respecter les délais et plusieurs améliorations sont déjà prévues pour la prochaine version.

## 1 Background on Polytechnique Montréal (PM)

Founded in 1873, Polytechnique Montréal (PM) is an important Canadian engineering teaching and research institution. Affiliated to the University of Montréal, it ranks first in Québec for the size of its engineering student body and the scope of its research activities. PM offers several programs in fifteen different specialties. The undergraduate programs are accredited by the Canadian Engineering Accreditation Board (CEAB), recognizing that the programs provide "the education necessary for licensure as a professional engineer in Canada" and also ensuring quality assurance and mobility (Engineers Canada, 2016). With currently approximately 8,000 enrolled students and counting more than 44,300 graduates, PM is alumni to nearly one quarter of the current members of the *Ordre des ingénieurs du Québec* (Québec's Order of engineers).

In recent years, PM has worked intensively to manage its activities in accordance with sustainability principles. In 2004, it adopted an *Environmental Policy* and, in 2011, its *Sustainable Development Policy*, a more inclusive engagement on social and economic aspects. PM has been reporting on these activities since 2004 and, in May 2016, adopted its new Sustainability Action Plan (2016-2020). The same month, PM also achieved Silver level accreditation in STARS (*Sustainability Tracking, Assessment & Rating System*) of the *Association for the Advancement of Sustainability in Higher Education* (AASHE).

## 2 Sustainability and PM

### *2.1 Environment and Engineering*

The long path towards integrating sustainability in future engineers' curriculum at PM started with the environmental dimension. As early as 1977, the civil engineering department decided to add a mandatory course on environmental aspects to its undergraduate program. To do so, a non-engineer professor, Dr. Claude Delisle, a biologist, was hired. At the time, this was considered a very bold decision. Dr. Delisle first developed a course on environmental impacts and, in 1978, the *Sanitary Protection Engineering* undergraduate specialty was modified to become the *Environmental Protection* specialty. These events were significant, since PM's civil engineering department "anticipated by almost twenty years the CEAB's Accreditation Criteria and Procedures" (Arpin *et al.*, 2013). Indeed, it would later become mandatory for all engineering programs to consider environmental and social impacts.

Environmental engineering content in the civil engineering program grew or contracted over the next two decades but, in 1986, in answer to CEAB's requirement that "all undergraduate engineering programs [have] to create a mandatory course specifically pertaining to the impact of technology on society" (Arpin *et al.*, 2013), a sociology course "*Technology and society*" was launched by PM. However, between 1985 and 1990, only a small part of this course was dedicated to environmental issues: a three-hour lecture. During this period, the Mathematics and Industrial Engineering Department, which offered multiple optional social science courses, became the "provider of "non-core" CEAB required courses for all undergraduate engineering programs" (Arpin *et al*, 2013).

In the 90s, recognizing the growing urge to act on environmental and social issues, many other optional courses were developed. In 1999, a first course specifically targeting sustainability issues (*Impacts and sustainable development*) was created, again in the civil engineering program. In 2008, an elective multidisciplinary capstone project course for fourth-year undergraduates (*Sustainable Development Capstone Project*) was proposed by Prof. Louise Millette. The objective was to "demonstrate that every engineer, regardless of his or her discipline, must be concerned with sustainable development" (Desjardins *et al.*, 2010). The enrolled students, to demonstrate their understanding of the integration of sustainability principles in their field of expertise, were asked to design ready-to-use examples to be used in one course of their undergraduate program. Although care was taken to discuss with the professors both content and form of their examples, uptake was minimal and the integration goal was not achieved.

In parallel, interest for integrating sustainability in the graduate curriculum also increased. In 2005, PM created five *Diplômes d'études supérieures spécialisées* (specialized graduate diploma) on aspects of sustainable development: Energy and Sustainable Development, Sustainable Design and Manufacturing, Environmental Engineering, Processes and Environment and Risks Management. In 2010, the program was restructured, and two new courses made mandatory (Desgroseilliers & Millette, 2013). They aimed at providing enrolled students of all disciplines the opportunity to develop a shared understanding of sustainability concepts, understand concrete applications in engineering and experience a certain level of multidisciplinary training. This course was later made available to fourth-year students as well.

### *2.2 Extension to Disciplinary Courses*

After 2008, CEAB updated its procedures and criteria for accreditation of engineering programs across Canada. The new requirements, still in effect, mandate that programs support the development of at least 12 attributes in their students, and ensure they demonstrate them at graduation. Legault (2014) identified fifteen learning objectives for sustainability in engineering education. CEAB's attributes cover the vast majority of them, some attributes meeting more than one objective (Table 1).

Table 1: CEAB's 12 mandatory attributes and the number of sustainability learning objectives linked to them (Legault, 2014)

| Attribute | Number of sustainability learning objectives linked to the attribute |
|---|---|
| A knowledge base for engineering | |
| Problem analysis | 2 |
| Investigation | 1 |
| Design | 5 |
| Use of engineering tools | 1 |
| Individual and team work | 1 |
| Communication skills | 2 |
| Professionalism | 1 |
| Impact of engineering on society and the environment | 5 |
| Ethics and equity | 2 |
| Economics and project management | |
| Life-long learning | |

This new requirement renewed the interest of all PM undergraduate programs for the inclusion of sustainability concepts in their disciplinary courses and made the process easier. An integration strategy was proposed by the Sustainable Development Office (SDO) and accepted by PM's *Academic Board* in 2015. The strategy requires, amongst others, that all programs include a three-hour disciplinary module on sustainability in their curriculum to ensure that all students share a body of notions on sustainability, and are able to address these issues in the course of their studies. SDO was mandated to support the programs in the development of their disciplinary modules.

### *2.3 PM's First MOOCs*

In 2014-2015, PM embarked on the creation of two Massive Online Open Courses (MOOC), thus joining an international movement aiming to offer easy to access and free online education. With a large part of its student body non-Canadian residents (more than 20% of the undergraduate level and 40% at the graduate level), PM already benefits from a strong international reputation. Developing MOOCs was considered a good opportunity to reach potential students and to strengthen PM's reputation by showcasing its expertise.

Two topics were thought to have a great potential for these courses: chemistry for engineers and sustainability in engineering. The Chemical Engineering Department started developing a MOOC on chemistry in late 2014. It was first launched in fall 2015 and a second edition ran in spring 2016. In February 2015, PM offered SDO the opportunity to lead the development of the MOOC on sustainability.

## 3 *PM's Sustainability* MOOC

### *3.1 Objectives*

The MOOC, titled "L'ingénieur, source de solutions durables"[3], was designed with several objectives in mind.

Firstly, the development of the course in itself was seen as an opportunity to gain knowledge and

[3] *Engineers: source of sustainable solutions* (our translation)

experience with this new media.

Secondly, the course allowed to reach a diversified audience, targeting three groups in particular: i) engineers needing to better understand their role in developing a more sustainable world; ii) future engineers wanting to get a picture of what can be done in engineering; iii) non-engineers interested in finding out what links may exist between sustainability and engineering.

Thirdly, with a high outreach capacity in the international French-speaking world, it was seen as a good opportunity to introduce PM's expertise on the subject.

Last but not least, the course would produce a wealth of pedagogical material usable by professors in their classroom or as stand-alone self-learning tools to help PM's students understand sustainability concepts in engineering. In fall 2016, the MOOC material will indeed be made available on a Moodle site, open to all students and teachers of PM. It is hoped that the various modules will be reinvested in existing courses and will help programs achieve PM's objective of strengthening the integration of sustainability in curricula.

### *3.2 Development Process*

The project was initiated without a specific resource allocation except for the support of one person: a "techno pedagogue" from PM's Teaching Support Center. The budget was not defined up front, but the instructions were to keep it as modest as possible. The project was therefore conducted 100% "in-house", bringing in a number of PM personnel. The web platform EDU*lib,* functioning on the open access version of edX, was chosen to host the MOOC as it was already the choice of the three campus partners: University of Montreal, HEC Montréal and PM.

A team comprised of one professor, one research associate and SDO's staff of two, assembled to develop the content, the members all the while maintaining their own regular activities. The total amount of time they collectively spent on the project is not yet known but will exceed 600 hours. This estimate does not account for the contributions of the "techno pedagogue", the technical resources, such as the IT team working on editing the videos, or the communications and marketing group. The time dedicated by the 20 experts, who prepared scientific content to illustrate their research and spent time being interviewed, is not counted either.

Although part of the development was carried out by specific entities of PM (chairs, research centres or institutes), the overall content was finalized by the development team.

### *3.3 Structure*

Scheduled to be released for the first time on September 14, 2016, *"DDI101 - L'ingénieur, source de solutions durables"* is a six-week MOOC. The course offers an overview of solutions developed and implemented in various engineering disciplines. After a first week of general introduction to sustainable engineering (definitions, concepts etc.), the following weekly topics are covered: sustainable energy, sustainable mobility, resources valorisation, sustainable production, and resilience of organisations and infrastructures.

Each week has a similar structure: strategic issues, tools used in engineering to understand and measure them, engineers' role, potential solutions, case-study and exam. In the case-study, two groups of fourth-year mechanical engineering students enrolled in their disciplinary capstone project are followed, as they go through the various stages of their projects. The goal is to illustrate how sustainability principles can be concretely integrated in the design process.

## 4 Challenges and Decisions

### 4.1 Scope

Sustainability is a vast and rich subject. One of the most difficult aspects was to decide on the scope of the content to make sure the course would be a good overview of the topic, without being too long, and would keep the students interested. Without surprise, the final content turned out to be more modest than initially thought of. Difficult but necessary compromises had to be made.

### 4.2 Contributors

At first, the contributors were chosen for their expertise in the topics selected for the MOOC and their willingness to participate. The vast majority of them expressed interest in the project, with only four out of the first twenty persons contacted declining the initial invitation. In the end, mostly due to scheduling conflicts, about 60% of them participated to the MOOC. Additional experts were later added, allowing the number of contributors to reach twenty.

### 4.3 An On-Line Course Is Not Your Typical Course

The lack of experience of most of the team members on how to develop efficient content for and with this new media was another important challenge. For most of the participants, the project was an entirely new adventure.

The first difficulty was to adapt highly technical engineering contents to the needs of a more diversified audience. Furthermore, the media also requires the content to be divided into short and logical units, a very different structure than that of a typical three-hour class. The length of almost all videos was indeed kept between five and ten minutes.

Speaking to a camera and explaining their field of expertise without a classroom proved to be a bit disturbing and out of their comfort zone for many participants. There is no student feedback, and the speaker must strive to look at nothing but the camera's lens. Not all the contributors used the same approach to deal with this unfamiliar context; some were very prepared and learned their script, while others improvised on their texts. The content team offered two options to the participants: being captured on camera presenting with a PowerPoint presentation as if teaching class material or being interviewed as experts using questions agreed upon beforehand. Although the final MOOC is a mix of both, the latter was the dominant choice. All agreed the interview format helped to keep the content dynamic, reduced the time spent in preparation and in front of the camera.

Coordination of the contributors' participation was a complex task as they had agreed to give time on a voluntary basis, in addition to already heavy workloads. Scheduling issues were numerous.

As each week closes with a short exam on the week's content, preparing the weekly evaluations proved a challenge. In the end, the content team took responsibility for most of them, as it provided coherence across the various contributions of the week, and throughout the entire MOOC. For this first version, the decision was made to use multiple choice questions only. Although the platform offers a great variety of options for student retroaction, there was no time left to take full advantage of them, and no resource identified for their monitoring once the MOOC would be on-line.

Editing the videos (finding appropriate illustrations, keeping the length of the videos in line with the objectives, adding graphics, titles and key words in support of the content, etc.) was also more time-consuming than initially foreseen and clearly underestimated by all team members.

## 5 Lessons Learned and Conclusion

### 5.1 *Focus on the Objectives*

With such a vast subject, it is easy to get lost. It was found very useful to always keep in mind the objectives of the MOOC and what the students should learn or remember from the course. In the case of PM, while developing the material, it was also essential to make sure that it would easily be usable in other contexts, in classrooms or as stand-alone videos.

### 5.2 *Adapt the Pedagogical Approach and Materials*

It was necessary to continually remind all participants that, for this new media, the material cannot be the same as the one used in a “classic” course and needs to be adapted. This requires time, efforts and humility. The help provided by the “techno pedagogue” to keep everybody on board was invaluable.

### 5.3 *Be Realistic and Do Not Strive to Perfection*

The contributors are not professional actors, hesitations are natural and perfection should not be pursued. With nowadays editing technologies, possibilities are infinite. After a minimum amount of editing steps (light, sound, adding key-words and illustrations…) it is important to quickly decide when to stop tinkering with details and accept the material as it is: excellent, but not perfect.

A MOOC is quite a project… It is worth being realistic when assessing the time, funds and efforts required to make it happen, especially if quality is important. Some published information can lead to believe very little funding is required; this is rarely the case (Conseil supérieur de l’éducation du Québec, 2015). There is always something that can be improved but is that little change worth the resources to do it?

### 5.4 *Putting Ourselves in the Shoes (or Headphones) of Future Students*

Getting some new perspectives and an objective fresh eye on the course material really helps keep the focus and facilitates the editing part. Asking students or young graduates for constructive critics can help, although it remains difficult because of the risk of hurting someone’s feelings. It is however essential to be able to tell if the material is too long or plain boring, and receive advice on how to modify it to ensure the student will stay tuned. Typically, the MOOC development team is **not** the target audience.

### 5.5 *Team Work Is the Key*

The workload is heavy and no team member is an expert in all the aspects of the adventure. It is important to be surrounded with contributors ready to help, motivated by this unusual experience and willing to share the ownership of the final product. Team work is really the key and, of course, with so many contributors working on quite a long timeframe, good communication and project management skills are more than helpful.

### 5.6 *In Conclusion: A Longshot but the Efforts Are Worthwhile*

The material developed for a MOOC can be useful in many manners. It can be broadcast several times and, in the end, the number of people reached can be quite impressive. It can be improved over time, integrating the students’ comments. Parts of the MOOC can be reinvested in other courses and used to support a variety of pedagogical initiatives. The project increases the overall expertise of all those involved.

A MOOC is also a wonderful way to showcase some of the achievements of the people of the institution. It can help support a sense of pride, not only for those directly involved in the project, but also for everyone since, by design, a MOOC is accessible to all.

For sure, creating a MOOC is demanding, challenging, overwhelming, and stressful but is a wonderful way to get started on what could be done next!

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# Cost effective educational test set up for car alternators

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## Abstract

A relevant teaching of electric generators and motors at all levels requires test set-ups. However, most of commercially available test set-ups and test set-ups with industrial components cost easily 5000 Euro and more, and are quite far away from everyday life in developing countries. However in a bachelor project a test set-up has been realized that combines a hand-held circular saw with a car alternator as a load which seems cost effective and closer to the everyday life in developing countries. The circular saw can be mounted in such way that torque can be measured using a weight, and the alternator can be connected to a battery. The circular saw is fed by a single phase transformer. The speed can be measured while using the frequency of the alternator, current and voltage are measured at the battery connection using multi-meters. Often the alternator and battery are recuperated, and the saw costs 100-200 Euro, the bench can be made using wood, a variable transformer costs 300 Euro, so a full test set-up could be made for less than 500 Euro.

## I. Introduction

In a world driven by business and trade, the necessity of test set-ups for machines cannot be overemphasized. For developing countries, necessity of cheap and cost effective set-ups is required as a driving force for development. Electrical power generation in vehicles is accomplished almost universally through the use of Lundell alternators which is still the prevalent electrical machine used as a generator in conventional vehicles due to its wide speed range, robust design and low cost. [1][2].

### *I.1 Alternator overview*

The car alternator is an electro-mechanical device that is the central component of an automobile's charging system. The alternator's sole purpose is to charge the car's battery and work alongside the battery to power the electrical components of the vehicle. An alternator is able to produce power via the electromagnetic relationship of its rotor and stator. [3]

The alternator contains:
A rotating field winding called the rotor.
A stationary induction winding called the stator.
A diode assembly called the rectifier bridge. A control device called the voltage regulator. Two internal fans to promote air circulation.
Brackets, bearings and pulleys.

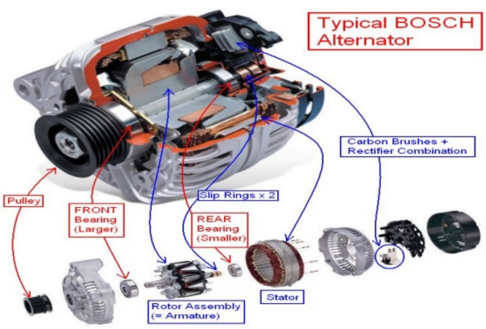


Figure 1: The alternator assembly

## II. Losses

No machine is perfect. Power is supplied to an alternator both in the form of electrical energy and in the form of mechanical energy. Whenever we convert one form of energy into another there are automatically some losses.

- Mechanical losses: Friction and windage
- Electrical losses: Copper losses: $I^2R$ losses in the stator and rotor winding
- Magnetic losses**:** Hysteresis loss in stator and eddy current loss in stator.

Percent efficiency is the ratio between the power out and the power in. [4]

$$Pout = E \times I \times 1.73$$
$$Pin = Pout + losses$$

If the load has unity power factor

$$Pout = E \times I \times 1.73$$
$$Pin = Pout + losses$$

## III. The cost evaluation and set-up test

### *III.1 Cost evaluation*

Sustainability is generally embraced and supported by policy and industry as a necessary path for development for that sustainable development needs to consider also economic and social aspects … [5]

The purpose of this project is to develop an inexpensive method to modify a car alternator for power generation. The process taken to accomplish this feat will make use of scrap materials commonly found in junkyards…[3] So, it is important to find a cost effective way and closer to the everyday life to do the set-up test. The materials used in this project are available and not expensive. A circular saw, regulator, transformer, multi-meters and alternator … which are existed in the laboratory. Often the alternator and battery are recuperated, and the saw costs 100-200 Euro, the bench can be made using wood, a variable transformer costs 300 Euro, so a full test set-up could be made for less than 500 Euro.

| Materials | Cost |
|---|---|
|  Circular saw | 100€-200€ |
|  | 8€-25€ |

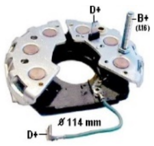
| Regulator | |
|---|---|
|   Rectifier | 35€-75€ |

Table 1: Prices of some used materials in the set up test

### *III.2 The set-up test and results*

In a bachelor project a test set-up has been realized that combines a hand-held circular saw with a car alternator as a load which seems cost effective and closer to the everyday life in developing countries. The circular saw can be mounted in such way that torque can be measured using a weight, and the alternator can be connected to a battery. The circular saw is fed by a single phase transformer. The speed can be measured while using the frequency of the alternator, current and voltage are measured at the battery connection using multi-meters.

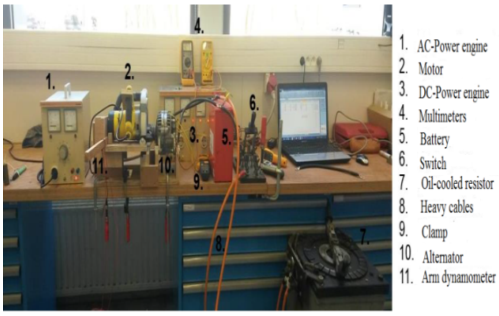



Figure 2: The set-up test

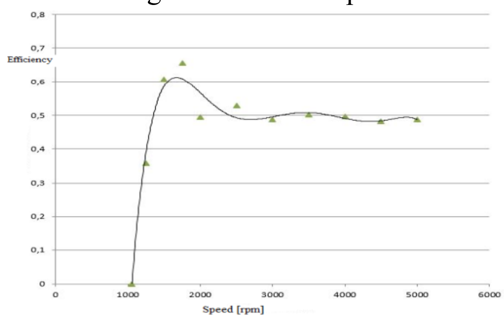



Figure 3: Efficiency in function of Speed

→In figure (3), between 1000 and 2000 rpm, there is always a limit which then drops slowly with increasing shaft speed.

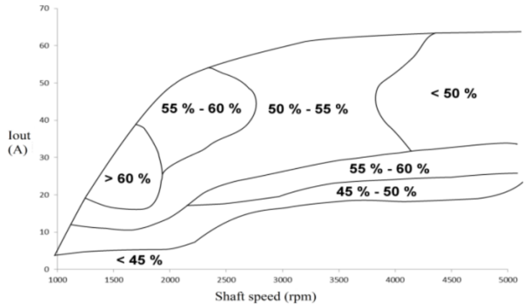



Figure 4: Current in function of speed

→To get a better view of the progress of the efficiency as a function of the speed and the current produced by the alternator, we have plotted it on a graph (Figure 4).

## IV. Conclusion

The magnetic losses and electrical losses in the stator have the greatest impact on performance.
There are some possible improvements like
Lamination of the claws, Limiting the stator current by a higher battery voltage and we can use of Schottky diodes.
This set-up test is a cost effective way to show torque and efficiency of an electric machine, it also shows that improvements are still possible in the area of automotive generator efficiencies.

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# INEA-ECOLÓGICA: An Educational Project for Sustainable Development.

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## 1 Introduction

INEA's Ecological Project is positioning based on the firm conviction that a new social paradigm is needed and the change has to come through a more friendly agriculture not only with the environment but also with the final consumer of agricultural products. INEA follows different actions to promote these changes in our region but we strongly believe that such changes must be global.

The main activity of INEA is teaching the Agricultural Engineering Degree. Our commitment, and at the same time innovative aspect, is to focus on sustainability and ecological agriculture without forgetting new technologies.

## 2 INEA's Ecological Project.

In order to describe in the best possible way INEA's Ecological Project, we are going to list some of the activities being carried out.

### *2.1 Academics. Degree in Agricultural Engineering, Post-Graduate Courses, Master.*

From 2010 the Agricultural Engineering Degree has been taught with a definite commitment with the Ecological Agriculture and Sustainable Development. Degree thesis are always on ecological themes; research lines in ecological agriculture; postgraduate courses on environment and rural areas in collaboration with Loyola's University in Andalucia, etc.

### *2.2 Urban Vegetable gardens project.*

(See the article in this Congress: Ecological urban vegetable gardens: INEA's lifelong learning Project, from the same group).

### *2.3 Organic Production: Crops and animal production.*

INEA has 25 hectares where different types of organic crops are tested. Besides, we try the response out of the crops to ecological production techniques as nutritional and organoleptic characteristics and qualities. In addition, INEA works in partnership with the associations "Cortas de Blas" and GANECA in the recovery, in an ecological way, of a native breed of hen: Castellana Negra.

### *2.4 Others*

#### *2.4.1 Come Sano Come Justo*

Come Sano, Come Justo is a cooperative on ecological products which also drives supportive projects. INEA is one of the partners of the cooperative and we also manage the shop they have downtown in Valladolid.

#### *2.4.2 I+D+i*

Several projects (e.g. on energy efficiency in agriculture) are being carried out in INEA either through agreements or collaborations on projects related with agroecology.

#### *2.4.3 Disclosure*

We have great interest to present our project and the results of our investigations. It is a way to raise public awareness that a world more respectful and fair to both the environment and among people is possible. This dissemination of information is carried out by: teaching, courses, publications (e.g. "*Ecocalendario*"), meeting points, and a great etc.

## 3 Results

1.-Our curriculum has just received accreditation to teach these studies by the National Agency for Quality and Accreditation (ANECA). Eco-labeling EU (European Union). Since 2012 the INEA's farm has European certification in agriculture, livestock and organic production. Organic products of the farm, INEA's orchard and the black hen eggs have increased their demand: increased sales.

2.-Each year the number of applications for urban gardens, BIOYANTAR sales and enrollment of students in the grade increase. This shows a growing interest in organic products and sustainability.

3.- Social Benefit.

- Well-trained professionals to put healthy foods in markets and respect for the environment and consumers; Support the local economy and sustainable employment. Boosting organic producers; Production of fresh food and better organoleptic characteristics; Improvement of quality of life and consumer safety by reducing the intake and contact toxic, often the origin of diseases and allergies; Contribution to rural development.

4.-Economic Benefit.

The main source of income in INEA is the Agricultural Engineering Degree. Since 2010 the number of students has increased by 15% annually. We could add to the aforementioned: postgraduate studies in sustainability of agriculture and agroecology, which have also increased the number of applicants; Income from certified organic products obtained at INEA's farm; Others income come from the participation in Local, Regional and National projects.

5.- Potential for replication.

The innovative character of good practice is completed with its effectiveness. Our project does not have specific impact but it will be seen in future actions. We are not only changing the way we produce. Producers and consumers are being taught for a better future. Therefore, the potential for replication derived from teaching, demonstration and dissemination, is huge.

6.- Collaborations

Collaborations have been achieved in the different parts and phases of the project: government agencies, agricultural cooperatives, research centers, companies and food producers, NGOs and foundations.

# INEA-ECOLÓGICA: An Educational Project for Sustainable Development.

M.I. González-Barragán, R. Rodrigo, P. Gutierrez, A. Gómez, A. Barrios, I. Guerrero

**Agricultural Engineering College, Valladolid University, Spain.**

**From INEA we want to invite all of you to a peculiar underground trip. Station by station we are going to show you our Educational Project: that combines the actions of agriculture and livestock farm, keeping in mind that the strategic aim of the project is our Degree. Education is focused on two different groups of people: the future producers (engineering university) and consumers (society).**

**Do you want to hop in?**

**5B LINE**

## First subway station: Introduction

**INEA was originally created with the purpose of promoting the professionalization of farming. Like other Agricultural College, the main objective is to teach technical knowledge of agronomy and students acquire the necessary knowledge to care and increase their production. What is usually not taught , (and is what differentiates INEA) is to care, protect and respect the environment. That is, taking responsibility for the consequences of our actions on the ecosystem.**

**Given the impact on the environment produced by conventional agriculture, INEA has been converted to organic and sustainable agriculture.**

**The main activity of INEA is teaching the Degree in Agricultural Engineering. Our commitment, and at the same time innovative aspect, is to focus on sustainability and ecology agriculture without forget new technologies.**

## Second subway station: Objectives

**1st That the next generation of food producers are persons with extensive knowledge and who understand the responsibility of feeding the population with quality food while looking after the environment.**

**2nd We want to show that responsible consumption that respects the environment and producers is possible.**

## Third subway station: Innovative actions

**INEA differs from others Agricultural Engineering Colleges in Spain for its ecological and sustainable model which is our identity trait. Students receive the same knowledge, but they are also instructed on the implications that these entail, as well as learning about more sustainable alternatives. In this way, our students will not only be efficient technicians in their work but people with ethical values and aware of the responsibility of providing food to the population.**

## Fourt subway station: INEA's Ecological Project

***Ecocalendario***

**(simply a calendar similar to a small notebook with texts about ecology)**

**Conection Line with :**

**Urban Vegetable Gardens Project**

**Animal Production**

**(recovery of a native breed of hen: Castellana Negra)**

**I+D+i**

**Crops (Vegetable production)**

**Degree in Agricultural Engineering, Post-Graduate Courses, Master**

**BIOYANTAR (ecological fairs)**

***Come Sano Come Justo***

**(cooperative on ecological products)**

**INEA Foundation**

**(grants, fresh food bank, etc.)**

**Disclosure**


## Last subway station: Results

1. Degree in Agricultural Engineering.
2. Applications for Urban Gardens, BIOYANTAR and students in the grade increases.
3. Environmental benefits of organic agriculture
4. Eco-labeling EU (since 2012)
5. Social Benefit
6. Economic Benefit
7. Potential for replication.
8. Collaborations

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# Integrated Project with Focus on Energy Transition and Circular Economy for Developing Engineering Students' Soft Skills

G. Léonard[1], A. Pfennig[1], D. Toye[1], C. Gommes[1], S. Lambert[1], N. Job[1], A. Léonard[1], T. Manfredini[2] and M.-N. Dumont[1]

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**Abstract**

The present work reports the experience of an integrated project developed at the University of Liege for master students in chemical engineering. The goals are to promote the acquisition of soft skills and to consolidate technical knowledge by integrating and linking chemical engineering disciplines usually taught separately. A case study was selected to address some of the challenges related to energy transition: students had to design the energy system of a remote island and make it as energy independent and $CO_2$-neutral as possible by 2030. The course of action during the academic year, the assessment of soft skills, and the tools offered to ease the mentoring and encourage the acquisition of soft skills are described. Not all implemented techniques performed equally well, and this project finally appeared to be a challenge for the teaching team as well.

## 1 Introduction and background

Over the last few years, University authorities, industrial partners as well as national and international experts that evaluated the education quality of our Department (AEQES, CTI) strongly suggested that opportunities should be offered to students to increase their soft skills as part of their curriculum. Moreover, many developments in chemical engineering are related to energy transition and circular economy, which are both transdisciplinary to conventional lectures. In this paper, we present methods and mentoring tools developed to teach students technical and soft skills for multi-disciplinary topics.

## 2 Description of the integrated project

Objectives and constraints were defined at the onset of the project for both technical and soft skills. The technical objective was to propose an energy system that would make Reunion Island as energy independent and $CO_2$-neutral as possible by 2030. This idea originated in the challenge set by the Eurecha 2015 student contest[1], for which students had to design facilities for a sheikhdom: electricity, water recycling, production of fertilizers… In our case, Reunion Island (~850 000 inhabitants) was considered as a case study as it is remote, has large biomass resources and high potential for renewable energies. Besides the objectives mentioned above and in order to force students to look at chemical engineering processes, the treatment of wastewater was imposed as well as the use of a synthetic liquid fuel as energy carrier. The targeted soft skills included working in large groups of minimum 4 students, efficient communication of results in English - both written and oral -, ability to integrate knowledge from various disciplines, development of critical mind and demonstration of independent and creative thinking.

## 3 Course of actions

A team of 8 professors and senior scientists mentored the project and contributed to its assessment. The 10-ECTS project was divided in two parts. In the fall semester, students made global energy balances to design the energy system that would fulfill the objectives. As a result, a Sankey diagram of the energy flows on Reunion Island by 2030 was produced to allow for an overview of the available Island's resources and needs, as well as of processes that can make the link between resources and needs. In the spring semester, two processes identified in the first part, namely the synthesis of bio-ethanol and bio-methanol, were modelled in more details using commercial software. Different tools were used to encourage student initiatives and work:

- The use of a **shared on-line portfolio** for students to gather their documents improved their internal communication, but this remained a marginal channel for communication with teachers
- In the fall semester, students **orally presented progress reports every two weeks**. After a feedback to students, the teaching team met to discuss the achievements and set the objectives for the next two weeks. This was very positive for the communication inside the teaching team. However, presentations every fortnight implied a work overload for students that had to constantly focus on preparing the presentations.
- From the beginning, students were strongly encouraged to **reach out to field experts** whose contacts were provided. However, they preferred to rely mostly on Internet as their main source of information and reached out only rarely for help and usually very late.
- In the fall semester, students had to designate **new team leaders in turn** every fortnight. This was abandoned as it prevented the establishment of clear structures in the group, reducing its efficiency.
- In the spring semester, **work tables** allowed students to work directly with the teacher specialized in their task. This was appreciated by students and teachers, and it needs to be further encouraged.
- **Help in the group organization and interactions** was provided by the PSGO (psychology of groups and organizations). This also included videoscopy, i.e. filming the students during their presentations and analyzing the records with them. This help was appreciated by students.

The assessment was based on **technical results for 60%,** and **soft skills for 40%.** The evaluation of technical skills was done partly by all teachers equally and partly by teachers whose expertise was the closest to the technical sub-tasks. For soft skills, efficient communication, creativity in the work and results and links with conventional lectures were assessed. Critical thinking was evaluated through the relevance of qualitative and quantitative results and discussions. Group work was assessed by the teachers as well as by students through mutual evaluation.

## 4 Conclusions and perspectives

The integrated project gave students a first opportunity to improve their soft skills along with their technical knowledge. It also improved their communication skills and their fluency in English. The teaching team proposed different mentoring techniques to encourage efficient work, with varying results. Finally, as the assessment ignored soft skills improvements, it may be modified by evaluating soft skills all year long so both the final result and the observed improvements contribute to the grade.

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Eurecha, The European Committee for the Use of Computers in Chemical Engineering Education, 2015. Announcement for student contest problem competition 2015. http://bari.upc.es/eurecha/.

# Integrated Project with Focus on Energy Transition and Circular Economy for Developing Engineering Students' Soft Skills

Université de Liège

**G. Léonard, A. Pfennig, D. Toye, C. Gommes, S. Lambert, N. Job, A. Léonard, T. Manfredini and M.-N. Dumont**

CHEMICAL ENGINEERING

## Abstract

We report the experience of an integrated project for master students in chemical engineering to **acquire soft skills** and address **challenges related to energy transition.**

Different teaching techniques were used and they did not perform equally well. This project represented **challenges for students** that had to master technical and soft skills, **but also for the teaching team** that needed to work together to follow up and assess students.

## Objectives of the integrated project

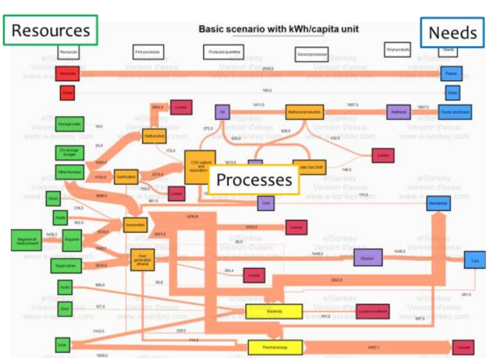
The case study was to **make Reunion Island as energy independent and $CO_2$-neutral as possible by 2030**.


Two **constraints** were set: wastewater treatment and use of synthetic liquid fuel. The targeted **soft skills** included:

- **Work in groups** ≥ 4 students
- Efficient **written and oral communication**
- **Integration of knowledge** from various disciplines
- Development of **critical mind**
- Demonstration of **independent and creative thinking**.

The 10-ECTS project was divided in two parts (1/semester):

- Propose a Sankey diagram of energy flows on Reunion Island in 2030.
- Model two processes identified in the first part, namely the synthesis of bio-ethanol and bio-methanol from biomass.




Sankey diagram of energy flows on Reunion Island by 2030[1]

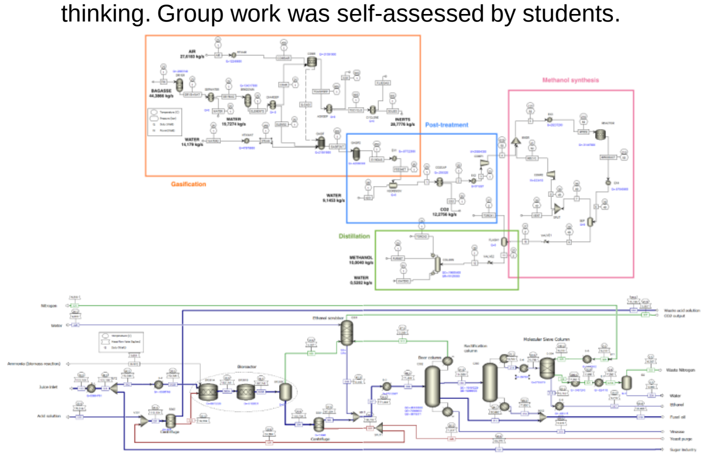
## Mentoring and assessment

8 professors and scientists mentored and assessed the project. Different tools to ease the mentoring and encourage the acquisition of soft skills were proposed:

| Impact of following idea on: | Students | Teachers |
|---|---|---|
| Shared on-line portfolio | *Good for internal communication* | *Not really used* |
| Presentations of progress reports every two weeks | *Work overload for presentations* | *Good for internal communication* |
| Agreement of field experts to be contacted | *Students rather relied on internet* | *No impact* |
| New team leaders in turn every fortnight | *Prevented clear group structure* | *No impact* |
| Work tables with teachers | *Efficient work* | *Efficient work* |
| Help in group organization from PSGO (Psychology of groups and organizations) | *Useful feedback* | *No impact* |

The assessment was based on **technical results for 60%,** and **soft skills for 40%:**

- Evaluation of technical skills was partly done by all teachers equally, partly by respective teachers in their field of expertise.
- Efficient communication, creativity, links with conventional lectures were assessed by all teachers, as well as critical thinking. Group work was self-assessed by students.




Process flow diagrams of the bio-methanol and bio-ethanol processes[1]

## Conclusions and perspectives

This project gave students a first opportunity to improve their soft skills along with their technical knowledge. Perspectives for next year's project include experimental work in addition to simulation work. Moreover, the assessment may be modified by evaluating soft skills all year long so both the final result and the improvement contribute to the grade.



## Reference

[1] Blanjean Q., Graindorge N.,Hardy W., Hendrickx H., Rocca C., Lekeane J., Van Callemont Q., 2015&2016. Reunion Island to an energy independent island. University of Liege

# Towards a Culture of Adopting Sustainable Energy at the Faculty of Physical and Mathematical Sciences at the University of Chile

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## Abstract

The question of how to be an energetically responsible citizen in the transition towards a zero emission economy is tackled in the present work. The experience of coming up with the Energy Master Plan of the Faculty of Physical and Mathematical Sciences at the University of Chile (FCFM UCh) is thus presented, in the context of the "National RoadMap 2050". The Energy Master Plan is focused in metering the electricity consumption, management of lightning and HVAC equipment, self-production of energy through photovoltaic panels in Campus, maintenance of electrical facilities, and evaluation of new electricity tariffs. A zero emission year and a personal emission quota of five tons per year per person are proposed for the transition towards a zero emission economy. Likewise, our work emphasises mainly on three aspects: Energy efficiency, on site renewable energy, and behavioural changes towards energetic sustainability.

## 1 Introduction

The context of this work is given by the National Energy Roadmap 2050 of Chile, which is conceived as a plan to design and execute a long-term Energy Policy that is socially, politically and technically valid in Chile. The main goal of the National Roadmap 2050 is to achieve a reliable, sustainable, inclusive, and at reasonable prices energy matrix. Specifically, the main objectives are:

- Reach a share of 70% of renewables in the energy mix of the country by 2050.
- Reduce tendering prices for power supply for homes, businesses and small businesses by 20% during the next decade in relation to the prices offered in the last tendering processes.
- Boost the development of NCRE (Non-conventional Renewable Energy) to fulfil the 20% goal for 2025.
- Develop the efficient use of energy as an energy resource to reduce the foreseen consumption for 2025 by 20%.
- Develop an Energy Development Strategy for 2035 and 2050 that is validated by the Chilean society.

In this transforming scenario, the Faculty of Physical and Mathematical Sciences at the University of Chile (FCFM UCh) has started a series of measures to bring a culture of adopting sustainable energy for all the community.

## 2 Faculty Energy Master Plan

This section explains the energy master plan to improve the energy consumption at the Faculty. To provide a view of the size of the problem, in the year 2015 the campus spent 7,6 GWh of electricity equivalent to a bill of around USD$ 1 million. The energy master plan for the FCFM includes 3 axes: metering, renewable energy, and energy efficiency. A description of each axis is given below.

The first axis deals with an accurate measure of the energy spending in the campus. To achieve this, a metering project, to update and enhance metering capabilities in different units, has been proposed. The project estimates that a constant metering of the energy consumed in each building requires the installation of 12 devices with an estimated cost of USD$ 10.000. The metering system also provides the knowledge of the energy curve in each building, which will provide useful information to detect excessive consumption and will facilitate the understanding of how the energy is used at the Faculty.

Secondly, in order to foster the assimilation of renewable energy among students and the community, a first photovoltaic plant was installed in May 2016, with a capacity of 15 kW. This plant uses a BIPV (building integrated photovoltaics) technology. Another initiative in this line is the implementation of a geothermal heating system, which is currently under evaluation.

The third line of work is energy efficiency, which is oriented to HVAC, lightening, and informatics consumption, as they are the more significant uses of electric energy in the campus. For HVAC devices a timer setting to close the HVAC circuits at night will be used. This action has already been implemented in the Electrical Engineering building, and as a result it led to savings of 25 MWh per year equivalent to 4% of the electricity consumption of the building. The full implementation could achieve saving of 60,4 MWh per year.

The informatics consumption is composed of 50% by computers. The desktop computers in all campus offices were configured in energy saving mode the year 2015, so they get suspended after 15 minutes of inactivity. The 80% of lightning consumption is by fluorescent tubes on campus. The change of these tubes to led illumination has a cost of around USD$ 200.000. Because of the high investment necessary to take this action it is discarded to be made at once, but is being implemented in a progressive scheme according to maintenance interventions at the Faculty.

## 3 Towards Sustainable Lifestyles

In (Dobson, 2011) the concept of the Sustainability Citizenship is defined as a person who believes:

- that sustainability is a common good that will not be achieved by the pursuit of individual self-interest alone;
- that ethical and moral knowledge is as important as techno -scientific knowledge in the context of pro-sustainability behaviour change;
- that other people's sustainability rights engender environmental responsibilities which the sustainability citizen should redeem;
- that these responsibilities are due not only to one's neighbours or fellow - nationals but also to distant strangers (distant in space and even in time);
- that is moved by other –regarding motivations as well as self-interested ones;
- that has an awareness that private environment -related actions can have public environment -related impacts;
- believes that market –based solutions alone will not bring about sustainability. The sustainability citizen will therefore recommend social and public action.

We fully agree with the above predicaments and the first action in that path would be to determine the carbon footprint of the Engineering School. The CO2 emissions at the Faculty have been calculated according to the Greenhouse Gas Protocol (World Resources Institute, 2004), and in year 2014 it reached 8.358 ton of CO2eq in total Annual Emissions. The final share of CO2eq emissions at the Engineering Faculty is shown in Figure 1.

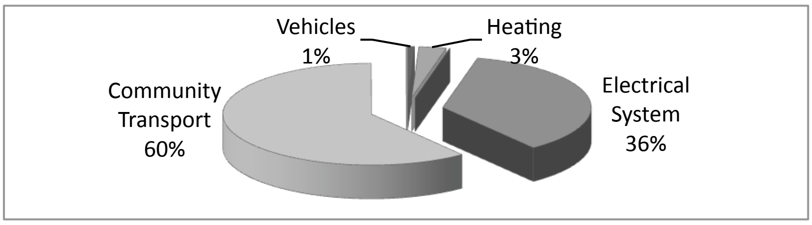


Figure 1: Carbon Footprint Calculation Distribution

Regarding sustainable energy, it is necessary to identify the patterns of behaviour of the community in at least terms of transport and electricity, as they are the main drivers for emissions. In this line, it is possible to find several studies concerning best environmental practises towards sustainable development, see for example (Dobson, 2007) and (Environmental Evidence Australia, 2012). In those studies practises of conservation programmes, environmental education, environmental health risks when making food choices, waste reduction, and environmental behaviour at the households, are presented.

In this context, it is very relevant to consider that there is strong evidence that giving people the chance to be responsible for and make choices about their environment produces environmental benefits that could not be achieved through conventional regulatory approaches (Barnett et al., 2005).

## 4 Conclusions

It has been identified that transport and electricity are key drivers for energy consumption in the Faculty of Physical and Mathematical Sciences at the University of Chile, therefore they are the main areas for stablish new policies for the adoption of sustainable lifestyles by the community.

The transition towards a sustainable lifestyle should be consistent with local CO2eq emissions and with the concept of sustainability citizenship, in order to give them the chance to be responsible for and make choices about their environment. The implementation mechanisms could include opportunities for civic engagement, grassroots innovation, and tools for community connection.

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# Approach & Practices for Life Long Learning in Engineering for Ecological Sustainability

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## Extended Abstract

Human society stands at a defining moment in history, torn between the rapid developments witnessed in engineering & technology on one hand, and its implications on the surrounding bio-diversity on the other. Modern society is faced with compelling planetary issues such as global warming, overpopulation, deforestation, natural resource depletion etc. Calling upon engineering scholars and professionals to devise action plans towards a sustainable future. Although several policies and awareness campaigns have already been introduced in the government and private sectors; one area that can possibly have wider implications is the review and re-structuring of the engineering curriculum, to emphasize the importance of studying sustainability. Additionally, also introduce innovative methods and practices in multi-national companies to continuously educate, implement and monitor employees' best practices towards a more sustainable economy.

In this poster, I would like to briefly discuss the importance of ecological sustainability and more specifically the key role played by engineering professionals. The poster will cover three main subjects, addressed under different sections with number of sub-divisions. Firstly, the importance of sustainability in engineering education will be briefly discussed. Later, elaborating on some reviewed schemes and practices to be introduced in the engineering curriculum. Next, the conceptualization of sustainable development will be touched upon. Here, whether sustainable development will be seen as environmental issue or considered as a multi-dimensional challenge will be explicitly examined. Lastly, to move from 'theory to practice', the subsequent section will outline the role and responsibilities of engineering firms and global technical organizations to promote eco-friendly business practices. Here, few of the good practices currently followed will be cited, with a discussion on some strategies that can be beneficial to the wider community will be presented. The main intention, is to highlight the importance of ecological sustainability in the rapidly developing technological world, to raise awareness and promote the role of engineers to create 'a globally safe environment for a better tomorrow', and make 'Modern technology a lifelong learning towards a healthy environment'.

There are several simple practices engineers (not just restricted to engineers, but applicable to all individuals) can personally adopt in their day-to-day activities to create a 'greener', 'safer' and 'healthier' society. One simple practice is to reduce the usage of goods; more specifically synthetic products that can result in waste generation, whilst encouraging the use of more re-cyclable goods. Although, managers and supervisors must promote good work practices within their teams and areas of management; the promotion and wider implementation of policies must be bought about my senior executives in the company. As an example: the adverse environmental impacts by the mobile phone industry can be reduced by focusing on sound management of its company operations, systematic supplier network management; and encouraging the inception of 'safe and environmental friendly phone designs' into the product and technology development cycles, with a focus towards innovation in 'sound end-of-phone-life practices' amongst its employees. Although the industry will play its role

in the later stages of an engineer; the need, duties, responsibilities and their key role played must be seeded at the very early stages of learning by technical universities.

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# Approach & Practices for Life-Long Learning in Engineering for Ecological Sustainability

*Poster by*

*Dr Arnesh Vijay*

## 1. INTRODUCTION

- Human society stands at a defining moment in history, torn between the rapid developments witnessed in engineering & technology on one hand, and its implications on the surrounding bio-diversity on the other
- Modern society is faced with compelling planetary issues such as global warming, overpopulation, deforestation, natural resource depletion etc
- Calling upon engineering scholars and professionals to devise action plans towards a sustainable future
- Although several policies and awareness campaigns have already been introduced in the government and private sectors—one area that can possibly have wider implications is the review and re-structuring of the engineering curriculum, to emphasize the importance of studying sustainability

## 2.SUSTAINABILITY IN ENGINEERING

- This subject covers a broad range of topics in engineering disciplines, including but not limited to electrical, civil, structural, environmental and architectural engineering
- The main intention here is to produce building structures, materials, places, equipments; goods and services in such a way that it lowers the use of non-renewable resources, minimizes environmental impact and relates people to the natural environment
- Some of the common topics for engineering focuses are : water supply, food production, housing and shelter, energy development, transportation, telecommunications…


## 3. SUSTAINBILITY ISSUES IN THE MOBILE INDUSTRY

- The European Commission's integrated Product Policy (IPP) approach is to reduce the environmental impacts from products throughout their life cycle; harnessing, where possible, a market-driven approach, within which competitiveness concerns are integrated
- Mobile phones have a complicated structure and material composition. Modern mobile phones consist of typically 500-1000 electronic/electrical components
- The commercial sources of these components can be situated anywhere in the world, resulting in supply management crisis in attempting to control environmental impacts
- The main phases of concern are in the extraction and processing of raw materials, components manufacture, transport of components to the phone assembly plant, phone assembly, transport of the phones to the distribution networks, use; and finally, the end-of-life cycle

## 4. ROLE OF ENGINEERS

- Role of engineers is imperative in creating technology which is appropriate and meets immediate needs for the long-term
- Engineers must have good understanding of the social, cultural, global and environmental responsibilities to employ principles of sustainable development
- Must have the ability to utilize systems approach to complex problems, and the capability to design and test operational performance
- Some examples :
  - Housing issues : Engineers can contribute in designing durable houses which can withstand, and equip people to manage natural disasters
  - Healthcare & Mobility : The lives of millions of disabled people can be improved by the cutting-edge innovations and inventions introduced in providing better accessibility services , devices and equipments to manage independently
  - Educating the local communities : Engineers have a long-term role in creating environmentally sound technologies and educating the community on how to use the technologies to boost their productivity and sustainability

## 5. ENGINEERING EDUCATION FOR SUSTAINABILITY

- The very fundamental yet important step is to introduce the topic of sustainability in the engineering curriculum; and educate young engineers on their role and responsibilities in achieving a sustainable future for the wider society
- Although basic topics are already in existence, yet, new practices, policies and procedure have to be introduced with substantial review of the existing curriculum
- Some of the key elements to address :
  - Raising the awareness activities
  - Revising and classification of programs
  - Organizing training programs/workshops for staff and students
  - Existing course/syllabus renewal: Example – good idea to classify the topics into different stages/levels. The topics of sustainability should be introduced at the very first year, with a gradual progression in the depth and content spread across the 3-4 years of technical study
  - New course development/replacement with changing times and advancement in technology
  - Outreach and bridging opportunities

## 6. CONCEPTUALIZATION OF SUSTAINABLE DEVELOPMENT

- Sustainable development can be analyzed as a multi-dimensional challenge in three dimensions : economic, environmental and social
- The sustainable development policy agenda focusses on processes and can extend to more cross-cutting technological and social system changes
- Environmental : Natural resource use, environmental management, pollution prevention (air, water, land and waste)
- Social : Standards of living, education, community and equal opportunity
- Economic: Profit, cost saving, economic growth and research & development


## 7. GOOD PRACTICES AT WORK

- Industries should raise awareness on sustainability and encourage employees to follow good practices at the work environment
- Some simple rules to follow :
  - Use goods which stop waste being generated ; Choose products which have minimum packaging and can be used productively and then recycled; Re-use containers, packaging or waste products wherever and whenever possible; Treat waste to make it less harmful or reduce the volume of the harmful component
  - For Managers and supervisors : consider sustainability issues when making plans and managing decisions; promote and encourage environmental awareness amongst employees; aim to continually improve environmental performance by identifying and addressing environmental risk; and make resources available to implement environmental risk management procedures

[1] Engineering for sustainable development: guiding principles
[2] Major challenges to engineering education for sustainable development: what has to change to make it creative, effective and acceptable to the established disciplines
[3] Sustainable business practices
[4] Lifelong learning for ecological sustainability and environmental justice
[5] Landscape ecology & sustainability
[6] The three dimensions of sustainable development - is an integrated approach beyond our reach

**ACKNOWLEDGEMENT** : Author would like to acknowledge that some pictures have been borrowed from Google images for the sole purpose of enhancing the presentation of ideas illustrated in this poster and not for any other reasons whatsoever

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# Wicked problem, Experience, Available-Resources, Solution-innovation (WEARS) method for Advancing Personalized Learning in Sustainability

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## Abstract

This research describes a methodological approach for developing sustainability-focused education termed: Wicked problem, Experience, Available Resources, Solution-innovation (WEARS). The WEARS method was derived from the analysis of ten previous stages of action research initiated from calls for faculty rigor in sustainability education, resulting in the description of *vignettes,* proposed to be important and distinct means of partially accounting for social-cultural considerations. The WEARS method is shown to be generalizable, therefore, action research does not have to be the adopted approach for sustainable engineering education or sustainable development research. The WEARS method accommodates traditional aspects of engineering education, specifically, the WEARS method draws from engineering education focused on innovation-change-wicked problems while also embedding philosophies associated with deep sustainability inline with outcomes to promote sustainable development. It is proposed the the WEARS method be applied as part of a graduate science degree program that builds upon exceptional undergraduate-professional achievement, inline with a University that maintains high academic standards, and that is purposeful towards the development of leadership.

## 1 Introduction

Previously, Jensen (2015) described action research as an approach of how to evaluate rigor in sustainability focused education when challenged by higher education faculty on the topic. Jensen (2016A) described interacting details of two exploratory stages as *vignettes* (creating analysis space *e.g.* for: individual perspective, social conflict, and professional mediation), that also led to the proposal of a generalizable education framework in community settings along the Front Range of Colorado (Jensen, *in eo*). This research describes an overview and first draft synthesis of four components as part of a proposed student intake, assessment, and education methodology. It is proposed that refinement of this methodology could be part of an education program with significant graduate level themes of Sustainable Engineering and Science. The four components of the proposed methodology involve; first - assessing support and available resources from all considerations keeping in mind safety, larger global impacts and the likelihood of great-risk great-award of proposed projects before students are accepted (Assessment), second - identifying a challenge or problem (*i.e.,* a so called Wicked problem) of great interest to a student, third - identifying experiences and education to be part of an individualized education path (Experience), and finally - would foster student driven outcomes relevant to the proposed area of inquiry (Solution-innovation). This poster will also shares progress in previously reported stages, the refinement of logic models that could be applied to program assessment, and pilot efforts with international students interested in sustainable engineering. Finally, an example course that builds on the larger body of research focused on teaching sustainable transportation concepts is briefly shared.

## 2 Development of a Sustainability Science Methodology

### *2.1 Rise of a Culture of Sustainability*

Previously identified programs (Jensen 2015) were briefly analyzed, programs were selected based on discussion with thought leaders among the researcher's community of practice. The community (*i.e.,* of faculty) suggested review of programs in order to gain insight into programmatic components demonstrating sustainability principles in higher education. It is apparent, that at the time, review of the United States community and literature indicate these institutions as leaders in advancing cultures of sustainability. Developing cultures of sustainability was a thrust of providing for education as part of the the United Nation's Decade of Education for Sustainable Development (2005-2014). Table 1 supports this previous suggestion with a brief and informal analysis of programs that were identified as prominent.

Table 1: A Google web search with the term: " X Sustainability" was performed, where X represents the following institutions; [1]Portland State University; [2]U. of Georgia; [3]U. Wisconsin; [4]U. Vermont; [5]U. San Diego; [6] Cornell; [7]Appalachin State University; [8]Emory; [9]Cal State Chico; [10]Dickenson; [11]Arizona State University; [12]U. New Hampshire; [13]Middlebury College. Based on the researcher's experiences, key terms and unique institutional practices are shared in this table. This information was obtained within a few clicks based on search results, indicating that it was somewhat easy to find and navigate to.

| | ***Key Finds*** | ***Product LCA*** | ***Capstone*** |
|---|---|---|---|
| 1 | MS and PhD Systems degrees, focus on infrastructure and social structure. | ? | ? |
| 2 | 17 h certificate, subject to the *three pillars* philosophy, several campus programs present. | No | Yes |
| 3 | 34 h Masters in Sustainable Management. | ? | Yes |
| 4 | MS Sustainable leadership, campus sustainable leadership (38 cert like programs!) | ? | ? |
| 5 | B.A. with field focuses and international experience. | No | No |
| 6 | 475 courses, Entrepreneurship and Energy focused programs-in traditional disciplines, large campus buy-in. | ? | ? |
| 7 | Several Sustainable Development B.A. and B.S. programs. | No | ? |
| 8 | Appearingly rigorous minor program, environment and climate, strong campus practice. International medicine incubator. | ? | Yes |
| 9 | Business minor with strong emphasis on global culture, discipline specific course offerings. | ? | No |
| 10 | Strong campus culture with unique campus programs, carbon action plan. | No | No |
| 11 | School of Sustainability with many degrees and sustainability in discipline titles. | Yes | Yes? |
| 12 | Dual 5 course major. | ? | Yes |
| 13 | Strong campus culture, environmental studies with global partnerships | No | No |

It was determined much of the sustainability curriculum that exists is of an arts nature[1], lacking in the rigor this researcher's community requested (Jensen 2015 and 2016A). Further, the researcher was aware that engineering approaches to sustainability were trending towards the incorporation of life cycle thinking and consideration given to the thought that Capstone projects should be a part of rigorous programs. As a participant in the 2015 Engineering Education for Sustainable Development Conference in Vancouver, British Columbia, the researcher became more aware of additional education programs adopting deeper philosophical perspectives[2] and programs.

## *2.2 Life Cycle Analysis as a Tool and Means for Deeper Decision Making*

The results from the previous analysis is therefore not surprising, in that life cycle analysis (LCA) and subsequently, Capstone projects, are not accounted for in strict arts based programs. Life cycle methods make use of hard sciences and engineering analysis to quantify environmental impacts that products and life cycles of products have upon the Earth. However, the implementation of Capstone projects appears to be more prominent, particularly notice the entrepreneurial program in Table 1.

Despite the measure that LCA perspectives provide, it is apparent that for example, some culture and belief systems do not accept these types of outcomes, and therefore contribute to the difficulty of incorporating deeper philosophical consideration of sustainable systems. The author is supportive of LCA methods. It is not proposed however, that stand alone LCA be regarded as a panacea. It is clear that sustainability (or systems) decision making is very complex and should not be designated to a few general categories (as recounted in Jensen 2016A). Generalized critiques suggest critical accounting for energy use outcomes, fair-accurate humanitarian considerations, and holistic cost accounting methods to alleviate gaps in practice. Valuation and quantification of the Earth's services is a state of the art endeavor. Consider Schaubroeck *et al*. (2016) which demonstrate an interpretation of physical environment characteristics that are valued. Regardless of a selected approach, the granularity of Earth-based measure and metrics (*i.e*., physical) in addition to knowledge and means of communicating ecosystem changes, is improving.

The largely accepted definition and focus of sustainability (*i.e.*, the epic goal offered by the Brundtland Commission) is not yet in place but still does seem to be a moderated approach to include the development of technology and policy that could lead to a more just, plentiful, equal, safe and healthy world. It is the authors contention that some of the most difficult challenges appear to be those of a social nature, for example; the abuse of the rule of law, lack of coordinated compromise toward change, and lack of humanitarian action.

## *2.3 Adopting Rigor*

As the researcher completes the original ten explorative stages, their presentation is modified here (Table 2) to be reflective of the WEARS method towards demonstrating broad and rigorous applicability. Each of the components will be further explored in a poster presentation for the EESD 2016 delegates. The fault in this synthesis is that it does not truly demonstrate the possibility of a global program *a priori* of the many rounds of research, discussion, and dissemination of this research. It is therefore, progressive towards the UNESCO-GAP (2016) in the hope that actionable outcomes can be realized.

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[1] The purpose of this report is not to review all programs with a sustainable education component or campus philosophy. For example, *The Journal of Cleaner Production* and the *International Journal of Higher Education in Sustainability* are two examples of periodicals with additional information on formalized assessments and campus reporting of activities that are being implemented in regard to sustainability. It is the focus of this paper however to synthesize a high quality and appropriate approach for a program based on the researchers experiences at his institutions and based on experiences within his own communities of practice.

[2] During this researcher's training, the Manhattan project is a grand example that demonstrates society's focus to achieve an ultimate goal that involved the development of technology. Readers are suggested to contrast this with examples of adopted technology that display unintended consequences and how such consequences can arise.

Table 2: Re-casting Jensen's 2015 accounting of action research stages in terms of the WEARs methodology.

| | Description | Wicked Problem | Experience | Available-Resources | Solution-Innovation |
|---|---|---|---|---|---|
| *Stage 1* | Innovative Education | UNESCO - GAP. | Teaching, community integration with Stakeholders | Schools, community, and government. | Education tool, environmental-sustainability literacy. |
| *Stage 2* | Innovative Education | UNESCO - GAP. | Teaching, community integration from higher education perspective. | Schools, community, and government. | Education tool and course. |
| *Stage 3* | Energy Technology Research | Limits to Conventional Energy Supplies. | National lab research. | Federal funding, mentorship. | Mentoring and research expertise for an international partner. |
| *Stage 4* | Food and Commmunity Systems | Need for Community and Humanitarian Capacity Building. | Grass root community development skills. | Land, officer responsibilities in professional non-profit. | Programming, membership benefits, land redevelopment, resource management program. |
| *Stage 5* | Small to Medium Sized Apartment Complex | Inefficient Energy Use. | Built environment technology, community development. | Wireless sensor technology, building. | Collect data for medium sized built environment. |
| *Stage 6* | Innovative Education | Holistic Sustainability - Resilience. | Proposal writing, follow through with sponsored project work. | University, State, and Federal funding. | Faculty development in rigorous sustainability topics. |
| *Stage 7* | Professional Development | Need and Call for Education Reform. | Develop professional relationships and expert credentials. | Federal funding. | Education outcomes - courses, teaching expertice, innovation. |
| *Stage 8* | Manufacturing Information Management | SME Manufacturing & Technology Transformation. | Bottoms up entrance to SME. | Freeware and computing resources for Android. | Infomration Technology and Software Application |
| *Stage 9* | Towards Materials Manufacturing & Performance Evaluation | SME Manufacturing & Technology Transformation. | Bottoms up entrance to SME. | Mfrg. tools engineering software. | Research related to the manufacturing of new materials. |
| *Stage 10* | Sustainable Transportation | Affordable and Efficient Indivdual Means of Transportation | Mechanical systems design. | Tools, equipment, used bicycles. | Unique means of transportation, insight for future design. |

The individual stages though general, represent large goals and challenges identified as important for social harmony (*e.g.,* education, manufacturing, transportation). It is expected that students would bring at least one developed skill set to a WEARs project. It is also assumed that students would be seeking to explore programs of study far more focused in a particular stage or two, that would also challenge them to develop additional inter disciplinary skills they do not already brandish.

## 3 Conclusions and Ongoing Research

Demonstration of the technical rigor that can be adopted in coordination with sustainability science will be a part of this researcher's teaching philosophy. As an example, Figure 1 shares the central focus of a proposed course in experiential transportation that will be shared later this year at an American Institute of Chemical Engineer's Conference in San Francisco (Jensen 2016B).

It is concluded that exploration of grass root and bottoms up change in Higher Education is not an easy undertaking. However, the body of this research demonstrates that ultimate commitment to larger global welfare in place of personal gain can result in the promotion of the elements that are often associated with the tenets of "Our Common Future" (Brundtland *et al.* 1987) and also means of inspiring innovation.

Another result of this research is the ongoing development of programmatic assessment that will be demonstrated on the poster. In particular, the means to assess product impact is considered appropriate, based on analytical outcomes from the rigor imposed on this research. Overall, substantial recent additions include; 1) manufacturing and transportation life cycles based on global pollution trends, 2) the emergence of Capstone projects, and 3) more robust education (for example, Table 1 demonstrates typical M.S. programs in one case - required 34 credit hours of academic accomplishment). It is noted that friends and colleagues interested in sustainability are increasingly inquisitive and aware of the chemical ingredients of new products (*e.g.,* quantum dot containing light bulbs[3]). Labelling and ecolabeling are specific topics in the realm and thoughts related to the EESD2016 theme of circular economy. The author can only comment that the synergism among product design, labels and means of creating circularity is apparent, and should be implemented and practiced by social participants.

Finally, a pilot study with international students that are interested in sustainable engineering will also be implemented in the near term to determine if similar projects and or courses would be a proper fit for the WEARs method. It is planned to make outcomes from the pilot study available online, students will drive interaction with their own communities to determine impactful outcomes.

Figure 1: Example low powered (*i.e.,* Loped) transportation via refurbished bicycles encumbered with an engine and instrumented with real time sensors-programmable controllers (*e.g.,* Arduino, 2016) provide for experiential learning tools with real world implications. For example: trends in providing for innovative transportation include: hybrid designs, emission controls, parts design, and characterization to garner improvement. The figure shows a real-time senor output and data logging to characterize the performance of the mechanical system (*i.e.* engine-exhaust temperatures). Not all global education settings have access to National Energy or Engine Laboratories, industrial partnerships, or open industrial partnership that support required student outcomes and therefore require appropriate means of education to support innovation. A simple version of this course could require as little as $250 of funding. Based on experiences with many levels of students, the skills gained in a mechanical and chemical systems course that make use of a Loped is ideal for individualized learning that teaches practical skills supported by theory.

[3] Quantum dots made of metalloid "cores" enveloped in a "shell" can be comprised of metals of concern, examples include: cadmium–selenium (CdSe), cadmium–tellurium (CdTe), and lead–selenium (PbSe).

## 4 Acknowledgements

Thanks to my mother Charlotte Jensen, as a life long educator she continues to teach and inspire me. Thanks to the American Institute of Chemical Engineers Sustainable Engineering Forum. Thanks to Dr. Nastassja Lewinski, Dr. Jiří Klemeš, and Dr. Donald Huisingh. Thanks to the United States Department of Energy and the Colorado School of Mines community.

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# LIST OF AUTHORS

# Annex - Programme in details

## Sunday, 4 September 2016

18h00 Doors open

18h30 Welcome session in the Gothic Hall

***Welcome on behalf of the City of Bruges***
by Mrs. Mieke Hoste, Alderman for the Environment in the City of Bruges

***Welcome to EESD 2016***
by Prof. Bernard Mazijn, conference coordinator
IDO vzw & UGent, Belgium

**Keynote:** ***Engineering Education for Sustainable Development – Why Are We Here?***
by Prof. Richard F. Vaz and Prof. Scott J. Jiusto, price winners EESD 2015
Worcester Polytechnic Institute, United States of America

19h30 Welcome reception in the Saloons of the City Hall

## Monday, 5 September 2016

08h30 Registration

09h00 **Opening Ceremony** (HOWest, Green Auditorium)
**Chair:** Prof. Luk Van Langenhove, Director UNU-CRIS and Professor at VUB-IES

***Opening address***
by Prof. Bernard Mazijn, coordinator EESD2016
IDO vzw & UGent, Belgium

***Major challenges to Engineering Education For Sustainable Development (EESD)***
by Prof. Nicholas A. Ashford,
Massachusetts Institute of Technology, United States of America

***Building a circular economy and analyse the implications for engineering education***
by Prof. David Peck,
Industrial Design Engineering at Delft University of Technology, Netherlands

***The context for sustainable higher education in Flanders***
by Mr. Filip Colson, Ecocampus
Government of Flanders, Belgium

10h30 Break

11h00 Sessions in parallel for oral presentations (break-out rooms at HOWest)

| **Stream A - Session 1**<br><br><u>Chair:</u> Prof. Gijs du Lain (UGent, BE) | **Stream B - Session 1**<br><br><u>Chair:</u> Prof. Richard Vaz (WPI, USA) | **Stream C - Session 1**<br><br><u>Chair:</u> Prof. Angélique Léonard (ULg, BE) | **Stream D - Session 1**<br><br><u>Chair:</u> Prof. Michel De Paepe (UGent, BE) | **Special Workshop I***<br><br>(pre-conference registration mandatory) |
|---|---|---|---|---|
| ***EESD and Circular Economy*** | ***Global issues in EESD*** | ***Overcoming barriers for EESD*** | ***EESD and Energy*** | ***Wicked problems*** |

12h30 Lunch

13h30 Sessions in parallel for oral presentations (break-out rooms at HOWest)

| **Stream A - Session 2**<br><br><u>Chair:</u> Prof. Karel Van Acker (KUL, BE) | **Stream B - Session 2**<br><br><u>Chair:</u> Prof. Luk Van Langenhove (UNU-CRIS & VUB, BE) | **Stream C - Session 2**<br><br><u>Chair:</u> prof. em. Rietje Van Dam (LEI, NL) | **Stream D - Session 2**<br><br><u>Chair:</u> Prof. Iris De Graeve (VUB, BE) |
|---|---|---|---|
| ***EESD and Circular Economy*** | ***Stakeholders in EESD*** | ***Life Long Learning*** | ***EESD and Disciplinary Approaches*** |

15h00 Break

15h30 Departure for the Concert Hall

16h00 **Debate 'Beyond the triple helix'** (Concert Hall, Chamber Music Hall)
**Moderator:** Robby Berloznik, Research Coordinator Technology and Society at VITO NV

'Beyond the triple helix' refers to an interaction beyond academia, industry and public authorities: other stakeholders should and will be involved in the debate to formulate the expectations towards engineers and their education, in particular when 'Building a circular economy together'.

***Keynote, introduction to the debate***
Prof. Walter Stahel
Founder-director of The Product-Life Institute Geneva (Switzerland)

***Members of the panel for the debate***

- **for the industry:** Guy Ethier (Senior Vice President, Umicore), Koen Sneiders (Recycling Manager, Derbigum), Geanne van Arkel (Head of Sustainable Development, Interface)
- **for the ngo's, EEB:** Leida Rijnhout (Director Global Policies and Sustainability)
- **for the trade unions, ETUC:** Benjamin Denis (Advisor Industrial policy and Sustainable Development)

***A first brief reflection from the floor regarding the statements by Jacques de Gerlache (Coordinator, The Greenfacts Initiative)***

18h30 Network Reception (Foyer at the Concert Hall)

19h30 Dinner (Forum at the Concert Hall)

## Tuesday, 6 September 2016

09h00 Sessions in parallel for oral presentations (break-out rooms at HOWest)

| **Stream A - Session 3**<br><br>Chair: Prof. Shady Attia (ULg, BE) | **Stream B - Session 3**<br><br>Chair: Prof. em. Kees Vromans (HAS, NL) | **Stream C - Session 3**<br><br>Chair: Prof. Jordi Segalas (UPV, ES) | **Stream D - Session 3**<br><br>Chair: Prof. Peter Goethals (UGent, BE) | **Special Workshop II***<br><br>(pre-conference registration mandatory) |
|---|---|---|---|---|
| ***EESD, Circular Economy and Design*** | ***Ethical and social issues in EESD*** | ***EESD: curricula, programmes and accreditation*** | ***EESD and Water et al.*** | ***Snowflake Education*** |

10h30 Break (incl. poster presentation)

11h00 Sessions in parallel for oral presentations (break-out rooms at HOWest)

| **Stream A – Session 4**<br><br>Chair: Prof. Adam de Eyto (UL, IE) | **Stream B - Session 4**<br><br>Chair: Prof. Scott Jiusto (WPI, USA) | **Stream C - Session 4**<br><br>Chair: Prof. Karin Edvardsson Björnberg (KTH, SE) | **Stream D - Session 4**<br><br>Chair: Prof. Aurore Degré (ULg, BE) | **Special Workshop III***<br><br>(pre-conference registration mandatory) |
|---|---|---|---|---|
| ***EESD, Circular Economy and Design*** | ***Social Responsibility in EESD*** | ***EESD and student evaluation*** | ***EESD and Biosciences*** | ***Social innovation*** |

12h30 Lunch

13h30 Departure for Greenbridge

14h30 **Presentations of the Local Academic Partners (UGent, ULg, VUB, ULB, KUL)**
**Moderator:** Dr. Chris Blommaert (Technum, Tractebel Engineering)

16h00 Break and technical visit in Greenbridge

17h30 Departure for Bruges

19h00 Belgium Night with beer tasting, food bar and cover band

## Wednesday, 7 September 2016

09h00 Sessions in parallel for oral presentations (break-out rooms at HOWest)

| **Stream A - Session 5**<br><br>Chair: Prof. Naoko Ellis (UBC, CAN) | **Stream B - Session 5**<br><br>Chair: Mrs. Nadine Gouzée (FPB & CoR-EU) | **Stream C - Session 5**<br><br>Chair: Prof. Pritpal Singh (VILLANOVA, USA) | **Stream C - Session 6**<br><br>Chair: Prof. em. Rietje Van Dam (LEI, NL) |
|---|---|---|---|
| ***EESD, Circular Economy and LCA*** | ***EESD and Transdisciplinarity*** | ***What is at the core of EESD?*** | ***Innovative teaching*** |

10h30 Break (incl. poster presentation)

11h00 **Plenary session** (HOWest, Green Auditorium)
**Chair:** Nadine Gouzée, Honorary Member Federal Planning Bureau & Full Member Club of Rome - EU Chapter

| |
|---|
| ***Part 1 (11h00 - 11h45): Short presentation (5') by authors of posters*** |
| ***Part 2 (11h45 - 12h30):***<br>***The SULITEST : a Global Assessment of Sustainability Literacy in Higher Education***<br>***Prof. Aurélien DECAMPS,***<br>***Assistant Professor at KEDGE Business School & Academic Coordinator of the SULITEST*** |

12h30 Lunch

14h00 **Closing ceremony** (HOWest, Green Auditorium)
**Chair:** Prof. Bernard Mazijn, IDO vzw and UGent

- Main findings of the Session Streams,
  short summary by the stream coordinators
- Building a circular economy in practice
  presentations by our private sector partners:
  - Mr. Koen Sneiders, Recycling Manager, Derbigum Derbigum
  - Mrs. Geanne van Arkel, Head of Sustainable Development, Interface
- Winners of the Leo Jansen Price and the EESD2016 Price
  (best paper and presentation; best poster)
- Announcement of EESD 2018

16h00 Goodbye afternoon drinks

# *Workshops

## Special Workshop I
## How do I know if my students can handle wicked sustainability problems?

*Svanström, Magdalena, Department of Chemistry and Chemical Engineering and Lönngren, Johanna, Department of Applied Information Technology, Chalmers University of Technology, Gothenburg, Sweden*

In engineering education for sustainable development, it is increasingly recognized that training on problem-solving needs to address ill-structured, wicked, real-world problems that are characterized by a high degree of complexity, open-endedness, and the presence of conflicting goals and perspectives. However, predominant engineering education practice rarely provides adequate training for dealing with these kinds of problems. Most engineering degrees provide students with ample opportunities to learn analytical, decompositional problem solving strategies. While such strategies are powerful tools for solving closed-ended, well-defined and decontextualized problems, they are not sufficient for dealing with wicked problems. Thus, engineering education practice would benefit from a greater focus on training students to deal with wicked problems. Efforts to address sustainability in engineering education naturally introduce opportunities to develop students' abilities to deal with wicked problems because most sustainability problems are naturally wicked. However, due to the fundamentally different nature of wicked sustainability problems and of traditional engineering textbook problems, it is not enough to simply change the subject content in engineering courses to include sustainability themes. Students need to actively develop skills such as integrative and iterative approaches to problem solving. To support such learning, educators need to develop new approaches in teaching and assessment.

This workshop aims to support educators in developing such approaches. Specifically, the workshop focuses on how to assess to what extent students are developing the desired skills. During the workshop, we will discuss some of the main characteristics of wicked sustainability problems and a preliminary set of intended learning outcomes for engineering education related to such problems. The main part of the workshop will be devoted to hands-on activities in which participants will discuss practical examples and generate new ideas for assessing these learning outcomes in their own teaching practice.

## Special Workshop II
## Teaching Sustainable Development: a Web Based Toolkit

*Jon-Erik Dahlin, Department of Energy Technology, Royal Institute of Technology (KTH), Sweden*

In this workshop you will get acquainted with the Snowflake Education toolkit for teaching sustainable development to engineering students.

The toolkit is a web based platform that enables teachers in various engineering courses to easily integrate a sustainability subsection into their subject courses. The toolkit includes a set of different classroom and off-classroom activities such as online lectures, homework assignments, coursework readings, computerised exams, and teacher instructions on how to give game seminars.

The user (teacher) chooses which activities to include in his/her course by checking boxes in an online web tool. A web page is then automatically created where the students can login to access course instructions, submit assignments, perform exams, and receive feedback from their teacher.

The toolkit is versatile and can be adjusted or amended according to the specific needs of the individual course it is used in. Or it can be used in its default format as a fully developed course-ready-to-use.

In this workshop we will demonstrate the Snowflake Education toolkit and some of the educational games included in the ready-to-use-seminars.

## Special Workshop III
## Social innovation

*Trainers from Oksigen Lab for Social Entrepreneurship*

Social innovation refers to tackling societal challenges with novel, more efficient, effective and sustainable solutions than the current ones. These novel ideas and solutions which create social value are often co-created (and financed) by non-profit, public and private actors. A circular economy provides a solution for important environmental challenges in our societies like pollution and waste management.

In this workshop we explore the interlinkages between the two concepts – social innovation and circular economy - on a theoretical and practical level, illustrated with cases. The profiles, competencies of these cases will serve as discussion input with and amongst the workshop participants. The two key questions of the group discussion are the following:

- Which functions are engineers taking up more and more in the creation of social innovative solutions to challenges related to material management, technical design and business modelling?

- How could engineering education prepare tomorrow’s engineers to play their role in social innovation in the best possible way?

# Partners

## Local Academic Partners

### Royal Flemish Academy of Belgium for Science and the Arts

### Ghent University

### Free University Brussels

### Université de Liège

### Université Libre de Bruxelles

### Catholic University of Leuven

### Institute for Sustainable Development

# Scientific Partners

## Belgium – Wallonia - FNRS

The Federal Institute for Sustainable Development (FISD) is attached to the Chancellery of the Prime Minister but falls within the competence of the Minister for Sustainable Development. Their mission includes – inter alia - the following responsibilities: the preparation of the federal strategy for sustainable development, the coordination of the implementation of this strategy and the provision of expertise.

## Belgium – Flanders - FWO

FWO supports – inter alia - researchers with the organisation of scientific conferences where the international and inter-university dimension is a central element of the programme. International scientific conferences are an important means of stimulating scientific debate, disseminating knowledge and developing informal networks.

# Partners in the public sector

## Diamond level

### Belgium - Federal Institute for Sustainable Development

The Federal Institute for Sustainable Development (FISD) is attached to the Chancellery of the Prime Minister but falls within the competence of the Minister for Sustainable Development. Their mission includes – inter alia - the following responsibilities: the preparation of the federal strategy for sustainable development, the coordination of the implementation of this strategy and the provision of expertise.

### Flanders - Environment, Nature and Energy Department

The Flemish Government aspires to create a better and healthier environment for present and future generations. The Environment, Nature and Energy Department takes the key position in the environmental administration. It is responsible for planning and evaluating the environmental policy in compliance with economic and social demands and for the co-ordination of all environmental actors as well as the implementation and enforcement of the environmental legislation in Flanders.

## Gold level

### Wallonie - Economie, Industrie Innovation, Numérique

The Walloon Government regards the circular economy is as an economic model that decouples economic growth from proportional growth in resource consumption. NEXT is a program for strengthening industrial policy within this context in order to develop the industry by generating growth projects for companies, creating jobs and wealth. One of the projects, Reverse Metallurgy, aims to create a platform of industrial, technological and scientific excellence in recycling.

### Belgium - Federal Public Service for Economy

In a fast-changing Belgian and international economic context the mission of the FPS Economy consists of creating the conditions for a competitive, sustainable and balanced functioning of the Belgian market of goods and services. In that respect the FPS Economy intends to fully understand and support the Belgian goods and services market in order to stimulate it even more.

# Partners in the private sector

## Gold level

### Derbigum

Derbigum has evolved from a traditional waterproofing producer into a new international player in ecological, sustainable and energy saving products and services. The baseline 'Making Buildings Smart' reflects our mission and vision : wherever possible make the building 'intelligent' so the available resources and energy are used sparingly.

### Eandis

Eandis offers network solutions for electricity, natural gas, heating and public lighting. The company also plays an important social role in achieving climate objectives, combating energy poverty and the independent management of energy data. Eandis is active in 229 cities and municipalities in Flanders and employs around 4 000 people.

## Silver level

### Interface

By definition, we are the world's largest designer and maker of carpet tile.
For us, Design is a mindset and sustainability is the journey of a lifetime.

## Bronze level

### Umicore

Umicore is a global player in materials technology. A solid international group, but every inch a Belgian company, with eight sites across the country. We develop technologies and produce materials for high-grade solar cells, rechargeable batteries, LED applications and catalytic converters. We recycle precious metals from laptops, mobile phones and more.

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